PERFORMANCE CHARACTERISTICS OF A 3" DIAMETER COMPOUND WATER CYCLONE

A Thesis Submitted
In Partial Fulfilment of the Requirements
for the Degree of
MASTER OF TECHNOLOGY

By
DEEPAK ANANTRAO RAWTAL

to the
DEPARTMENT OF METALLURGICAL ENGINEERING
INDIAN INSTITUTE OF TECHNOLOGY, KANPUR
MARCH, 1978

ME-1978-M-RAW-PER

CERTIFICATE

This is to certify that the work presented in this thesis entitled 'Performance Characteristics of a 3'' diameter Compound Water Cyclone' has been carried out under our supervision and it has not been submitted elsewhere for a degree.

Spmehrotra

Dr. T.C.Rao
Professor and Head
Department of Fuels, Chemistry and Metallurgy,
Indian School of Mines
Dhanbad - 826 004

Dr.S.P. Mehrotra
Assistant Professor
Department of Metallurgical Engineering
Indian Institute of Technolo
Kanpur-208016

ACKNOWLEDGEMENT

I express my deep sense of gratitude to Dr. T.C.Rao for his kind help and encouragement during the initial stages of the project.

I am grateful to Dr. S.P.Mehrotra for his invaluable guidance and suggestions during the course of investigation. It was really difficult to see the project a completed one without his guidance.

I am also thankful to Dr. A.K.Biswas for extending the facilities of Surface Chemistry Laboratory.

Thanks are due to Mr. S.C.D.Arora for his cooperation, to all the friends for their help during the work. Thanks are due to Miss C.Komala for her elegant typing and to Mr. V.P.Gupta for drawing neat sketches.

Finally, I wish to thank all the others who directly or indirectly helped me during the work.

D.A. Rawtal

CONTENTS

LIST OF FIGURES AND TABLES

Table

NOMENCLATURE

A area of feed inlet

D_c hydrocyclone diameter

D_i feed inlet diameter

D_o vortex finder (overflow) diameter

D_u spigot (underflow) diamete

$C_1, C_2, C_3, C_4, C_5, C_6$ and C_7 constants

d size of the particle

d_{50} size of particle having actual efficiency of 50 percent

d_{50c} size of particle having corrected efficiency of 50 percen

$E_a(d)$ actual efficiency of size d

$E_c(d)$ corrected efficiency of size d

Er reduced efficiency

F feed flow rate of the pumps

f prefix for feed stream

h depth below the surface

$K, K_1, K_2, K_3, K_4, K_5$ and K_6 constants

O/F overflow

P feed pressure

PW percent water in feed pulp

Q throughput of the cyclone

R_f percent feed water to underflow

t time

u prefix for feed stream

U/F	underflow
WF	water rate in feed stream
WOF	water rate in overflow stream
W_S	mass flow rates of solids
x, x_1	constants
α	constant
$-53\ \mu$	particles of size-53 microns
ρ_S	specific gravity of solid
ρ_L	specific gravity of liquid
η	viscosity of the fluid

ABSTRACT

Performance characteristics of a 3'' compound water cyclone having different vortex finders of 11.10 mm, 12.90 mm and 19.32 mm diameters and spigots of 11.54 mm, 12.10 mm and 12.8 mm diameters were studied using three different materials, namely, calcite, silica and coal. A slurry of constant pulp density was introduced at a constant flow rate and the overflow and underflow were corrected at regular intervals of time. These samples were then analysed for solid and water weights in overflow as well as in underflow. The size analysis of collected solids was made using Andreasen Pipette. The throughput of the compound water cyclone was found to be a function of vortex finder, spigot and materials. Following relationship was found to be applicable

$$Q = K_6 (D_o)^{0.678} (D_u)^{0.24}$$

Distribution of water in overflow and feed agreed well with the following equation

$$WOF = x_1 \log WF + C_7$$

In this equation x_1 is independent of vortex finder and spigot diameters but varies with nature of material used whereas the constant C_7 depends on spigot diameter and material. The actual, corrected and reduced efficiency curves for compound water cyclone were found to be of same nature as for a hydro-

CHAPTER 1

INTRODUCTION

A cyclone is a piece of equipment, which utilises the fluid pressure energy to create rotational fluid motion, and causes the centrifugal separation of materials contained in the liquid fed to it. It consists of a cylindrical top part joined to a conical bottom with a cone angle of about 20°. It has two outlets, namely, overflow outlet (vortex finder) and underflow outlet (spigot) provided at the top and bottom of the unit, respectively.

The feed in the form of pulp is introduced under pressure tangentially through a feed inlet positioned at the cylindrical top of the cyclone where it is subjected to the influence of dual spiral flow pattern as shown in the Fig. 1.1. This results in separation in the cone of the cyclone by the action of centrifigual and centripetal forces. The coarse and heavier particles selectively enter the outer spiral and then get discharged through the spigot while the lighter and finer particles, together with the major portion of the feed media enter the inner spiral and get discharged through the vortex finder.

A cyclone is called 'Hydrocyclone' when water is the fluid medium. The hydrocyclone can be categorised as: (i) Classifier, (ii) Washer, (iii) Thickener and (iv) liquid-liquid separator depending on the task it is supposed to perform.

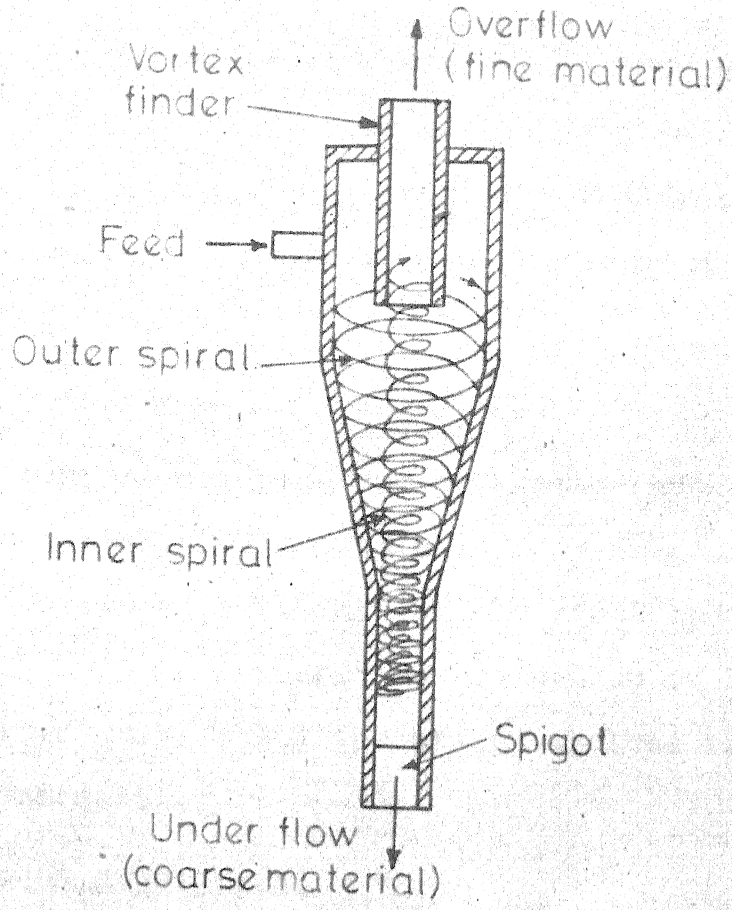

Fig. 1.1 -Centrifugal classifier-cyclone.

1.1 Cyclone as a Classifier

A cyclone which separates solid from solid according to size is referred to as a classifier. The required duty in this case is to maximise removal of suspended solids which are above a given size and minimise removal of those below this size.

1.2 Cyclone as a Washer

A cyclone carrying out separation according to density is usually referred to as a 'Washer'. In this case the separation of materials of different specific gravity is achieved in a suspension of medium of intermediate specific gravity and the use of cyclone results in sink-float separation.

1.3 Cyclone as a Thickener

A hydrocyclone which is used for separating solid from liquid is known as a Cyclone thickener, and is designed for maximum removal of suspended solid from ~~suspended~~ liquid. The cyclone is most usefully applied to the separation of particles in the 5 to 200 μ size range.

1.4 Liquid-Liquid Separator

This is more recent application of the hydrocyclone. The separation of immiscible liquids in the cyclone is equally as feasible as the separation of solids

from liquids. It is inevitably, however, more difficult. The reasons are that density differences are generally smaller and the existence of shear can cause the break-up rather than coalescence of droplets of the dispersed phase.

1.5 Cyclone Washers

The application of washers (water cyclone) dates back approximately ten years, following its development at the Dutch State of Mines[1]. It differs from the classifiers in the sense that here in this the medium of separation used has the density in between the density of two solids, for example, to separate coal (Sp.Gr. 1.4) from Shale (Sp.Gr.1.7) a medium of specific gravity 1.5 is found to be quite effective. Another feature of this cyclone is its ability to carry out specific gravity separations merely by suspending material with fines content in water. The fines recirculate and build up to give the required medium within the cyclone.

1.6 Working Principle

The material is fed to the cyclone alongwith suspension. Due to the thickening effect of the cyclone a working bed is formed in which the suspension particles are kept in equilibrium between the centrifugal forces and dragging forces of water current. Particles lighter than the effective specific gravity of the established washing

bed are swept away towards the outlet opening (vortex finder) and the heavier particles than the specific gravity of the washing bed, leave the cyclone at the apex. In another words the lighter particles form a block whereas the heavier particles, due to their higher density, readily migrate through the bed.

The performance of cyclone is mainly affected by spigot dia. vortex finder dia., cone angle, cyclone dia. etc. So while designing a cyclone washer these factors must be taken into consideration. Staas(2) found that the float product yield and specific gravity of separation increased with increase in overflow diameter. Whilst they both decreased with decrease in spigot diameter or underflow diameter. It was also found that the wide cone angles are most beneficial for building up a stable suspension by recirculation and thus giving separation at higher specific gravity than that of suspending medium present in the feed.

Study of the separating mechanism(3) has indicated that the water cyclone when used as a single unit, is inadequate for practical cleaning because it either produces a clean coal and a poor refuse or vice versa (in case of coal cleaning). The use of water cyclones in series alongwith the number of pumps and mixing tanks has not been found to be economical. This, therefore, led to the

development of a new type of washer known as compound water cyclone.

The compound water cyclone is a washer having compound bottom (Fig. 1.2). It differs from washer cyclone in the sense that in the case of compound water cyclone the bottom is having different angles whereas in the case of washer the bottom is not compound but simply conical (with wide angle of cone). The compound bottom of the cyclone results in better and faster cleaning.

1.7 Separation mechanism in compound water Cyclone[.4]

A cross sectional view of the compound water cyclone is presented in Fig. 1.2 to illustrate the separation of raw coal specially. Particles of different sizes and specific gravity form a hindered settling bed in Section I of the compound cone. Light coarse particles are prevented from penetrating the lower starta of this bed by the coarse heavy fractions (middlings and refuse) and by the fine particles filling the interstices of the bed. Consequently, the water passing from the periphery of the cyclone chamber toward its main outlet (the V.F.) erodes the top of the stratified bed and substantially removes the light coarse particles via the ''Central Current'' around the air core (vortex).

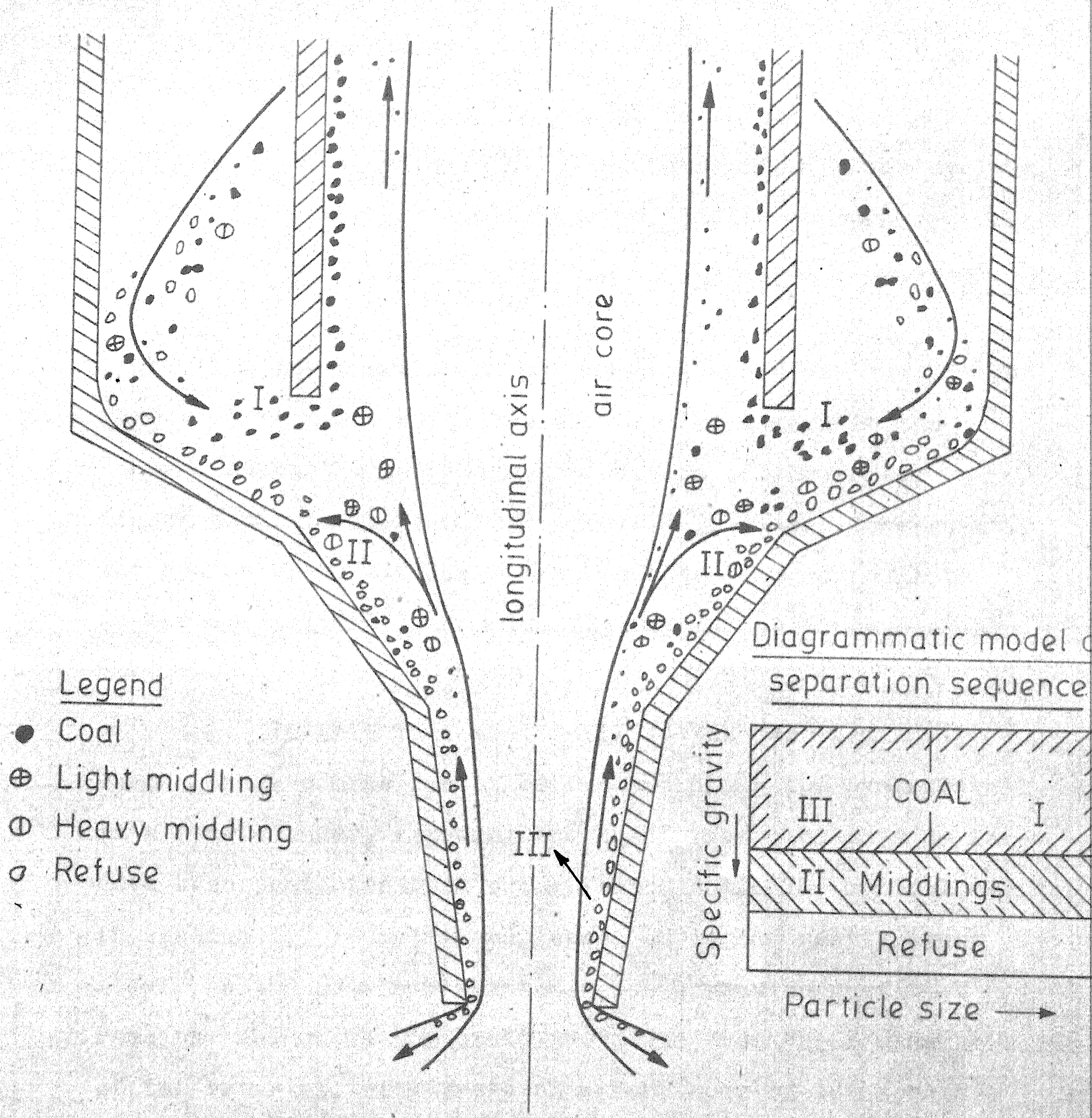

Fig 1.2 - Separation mechanism in the compound water cyclone (Ref. 4).

The remainder of the bed is forced into second conical section (II) by new feed entering the cyclone, substantially without losing its stratified character. Here, the central current is much stronger and erodes the top of the bed where the middlings are now exposed. The light middlings are swept up and discharged via the vortex finder. The heavy middlings that spiral upward in the central current may by pass the orifice of the vortex finder owing to their higher specific gravity. Consequently, the coarse heavy middlings fractions tend to recirculate to the stratified bed and finally enters the third conical section.

In this last section (III) the bed is finally destroyed as coarse particles fan out along the cyclone wall in a single layer, exposing the small particles that so far have been protected from being washed out. The central current in section III is relatively weak, as it has nearly spent itself in the previous section. The upward current that remains, separates the small particles from the remainder of the material, with preference for those of low specific gravity. Thus, the fine light particles are finally discharged through the vortex finder by a process of elutriation. The refuse, fine as well as coarse, is ~~divided~~ discharged through the apex. The separation thus takes place in three steps, as summerised in a diagrammatic model Fig.1.2.

The choice of compound water cyclone is found to be dependent on the type and top size of the material to be washed out. The other important operating variables are: (i) vertical clearance between the lower orifice edge of the vortex finder and the compound cone, (ii) the vortex (air) diameter, (iii) the apex diameter, (iv) the concentration of solids, and (v) the inlet pressure etc. Although some literature is available on compound water cyclones, the data for its design (similar to that available for classifier cyclone) is lacking. It is possible that some of the design criterias available for classifier hydrocyclones may also be applicable as it is or in modified form for compound water washers. But before applying them in practice their validity for compound washers must be thoroughly examined. In the present investigation an attempt has been made in this direction. The performance characteristics of laboratory size compound water cyclone has been studied with an ultimate objective to derive some scale up equations for the design of compound water cyclone.

CHAPTER 2

LITERATURE REVIEW

As the objective of present investigation is to study the performance characteristics of laboratory size compound water cyclone on the lines similar to those for classifier cyclones, an attempt has been made in this chapter to review the literature on performance characteristics of classifier cyclone. For convenience the performance characteristics have been discussed under these sub-headings, (1) capacity of hydrocyclone, (2) water distribution, and (3) efficiency of hydrocyclone.

2.1 Capacities of Hydrocyclone

One of the most widely studied performance of cyclones has been their capacities. It has been generally observed that variables like the cyclone inlet, vortex finder dimensions and the operating pressures affect the capacity of a cyclone. Dahlstrom [5] found experimentally that

$$\frac{Q}{F} = K_1 (D_o . D_i)^{0.9} \tag{2.1}$$

where Q is the throughput in gal./min. D_o is the vortex finder diameter in inches, D_i is the inlet diameter in inches, K_1 is the constant, and F is the feed flow rate of pumps. The proportionality constant K_1 was primarily found to be a

function of included angle of the cone and minor design variables. Kelsall[6] observed that in a laboratory equipment on a 3'' cyclone

(i) the capacity varied as $(\text{pressure})^{0.416}$, and

(ii) decrease in the spigot diameter at constant feed pressure had negligible effect on total flow through cyclone. On the basis of data from operating units in industries Chaston[7] proposed a simple expression relating throughput to feed pressure.

$$Q = K_2 A\sqrt{P} \tag{2.2}$$

where K_2 is constant, A is the area of feed inlet in sq. inches, and P is the feed pressure in lb/sq. inch.

The above expressions have been found suitable for estimating the capacity of a cyclone treating pulps of low solid content (10-20 percent solids by weight). Fahlstrom[8] investigated the effect of solid content (0-40 percent) of the pulp on the cyclone capacity and observed that the capacity increased with increase in pulp density and decreased with increase in spigot diameter.

Recently, Lynch and Rao[9] reported that vortex finder diameter, feed pressure, and solid content of the feed could be related to throughput as

$$Q = K_3\ (D_o)^{1.0}(P)^{0.5}(PW)^{0.125} \tag{2.3}$$

where K_3 is a constant and PW is percent water in feed p pulp.

They also observed that change in spigot diameter did not have significant effect on the hydrocyclone capacity.

An expression for throughput as a function of vortex finder diameter, inlet diameter, spigot diameter and feed pressure etc. has also been proposed by Lynch and Rao(10)

$$Q = 15.63\ (D_o)^{0.68}(D_i)^{0.85}(D_u)^{0.16}(P)^{0.49}(-53\ \mu)^{-0.35} \qquad (2.4)$$

where $(-53\ \mu)$ are the particles of size - 53 microns.

All the above expression are empirical in nature. The various constants and exponents involved in these expressions have been derived either graphically or by regression analysis.

2.2 Water Distribution

Peachey(11) has observed a linear relationship between tonnages of water in overflow and feed water from the data collected from operating units in industries. He found water rate in overflow stream to be dependent only on the spigot diameter size and independent of all other operating and design variables. Similar observations was

also made by Lynch and Rao[9] and they quantitatively expressed this as,

$$WOF = WF - 10\ D_u + K_4 \qquad (2.5)$$

where WOF is the water rate in overflow stream in tons/hour, WF is the feed water rate in tons/hour, and D_u is the spigot diameter in inches, and K is the constant. It was pointed out that results of atleast one classification test were required to determine K_4 in the above equation. However, recently Kanungo and Rao[12] generalised the above expression as

$$WOF = 1.06\ WF - 8.74\ D_u + 6.02 \qquad (2.6)$$

However, for small diameter cyclones treating dilute pulps expressions of the following form [13,14,15] have been found to be more suitable.

$$1-R_f = C_1 /\ 1+C_2(D_u/D_o)^x \qquad (2.7)$$

where R_f is the flow ratio (underflow rate/feed rate); C_1 and C_2 are constants approximately equal to unity and D_o is the vortex finder diameter and x has value between 3 and 4.

2.3 Efficiency of Hydrocyclone Classifier

As the feed to the classifier contains particles of various sizes, it is not possible to define the efficiency of classification by a single number unless classification is ideal. The classification in a cyclone as in any equipment which depends on relative motion between fluid and solids is dependent on probability. It, therefore, follows that classification is not sharp and coarse material must be accepted with the fine material or fine product with the coarse product even if precautions are taken to minimise short circuit flow or underflow liquid. The actual efficiency of separation mathematically defined as[16]

$$E_a(d) = \frac{u^{f(d)} \quad u^{WS}}{f^{f(d)} \quad f^{WS}} \times 100 \qquad (2.8)$$

where f(d) denotes frequency distribution by weight and WS is the mass flow rate of solids in the stream denoted by the prefix. The actual efficiency for particles of size d is graphically represented by the performance curve as shown in Fig. 2.1 which relates the weight fraction or percentage of each particle size reporting to underflow discharge to the particle size preferably measured as diameter of spherical particle with same settling rate. The classification point can be chosen any where along

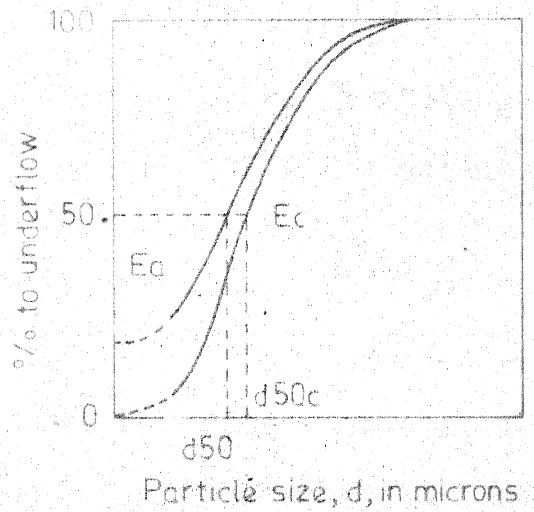

Fig. 2.1 Typical efficiency curves, actual (Ea) and corrected (Ec)

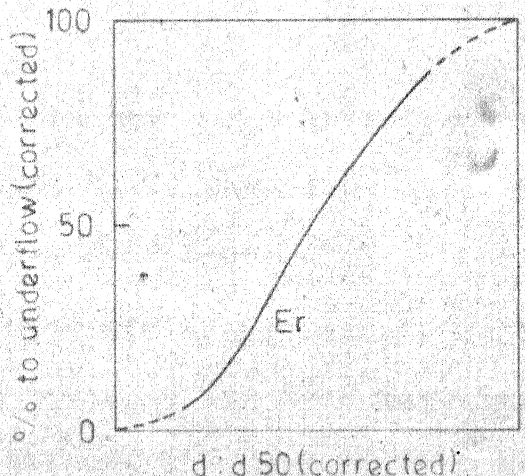

Fig. 2.2 Reduced efficiency curve (Er)

this curve with the choice of position depending on the relative importances of the need for the removal of un-desirable fraction or the recovery of the desired fraction.

Truely speaking the actual efficiency curve should pass through the origin but in reality it does not. An explanation for this behaviour has been given by Kelsall[17] who suggested that even in the absence of the centrifugal forces acting on the particles a fixed percentage of particles of all sizes will be discharged through the spigot. Therefore, the separation due to centrifugal action alone, termed as centrifugal efficiency or corrected efficiency, is given by

$$E_c(d) = \frac{E_a(d) - R_f}{100 - R_f} \times 100 \qquad (2.9)$$

where $E_a(d)$ is the gross efficiency or measured or actual efficiency, and R_f is the flow ratio, i.e. volumetric ratio of underflow to feed flow.

So the corrected efficiency can be defined as the fraction which is separated to the feed material which presents itself for classification.

It is meaningless to quote efficiency without reference to size or size distribution. It is inconvenient

to quote a graph. Consequently one point on this graph has become a useful reference point for defining the performance of a cyclone. This is that particle size which gives a centrifugal efficiency of 50 percent; i.e. the particles of that size which appear 50 percent in underflow as well as 50 percent in overflow. This size is known as d_{50} and illustrated in Fig. 2.1. Another term 'size of separation' defined by Dekok[18] has also been used for expression of plant results. It approximates to d_{95}, the particle size which exhibits a centrifugal efficiency of 95 percent.

However, the two efficiencies, namely, actual and corrected have the draw back that they are fully dependent on the operating parameters like vortex finder diameter, cyclone diameter, pressure etc. and the material to be used. So a new efficiency term known as reduced efficiency which does not depend on the design parameters and operating conditions has come into picture. It is defined as a measure of the probability of appearance of particles in the coarse product due to the centrifugal action alone. One major advantage of reduced efficiency curve is that a curve determined for a mineral on a small cyclone can be used for scale up work.

Fig. 2.2 shows a reduced efficiency curve derived from Fig. 2.1. Here weight percentage corrected of solids appearing in underflow is plotted as a function of actual size (d) divided by d_{50c}, the particle size (corrected) which reports in equal fraction to both underflow and overflow. An empirical expression for the reduced efficiency curve given by Lynch and Rao[9] is

$$E_c(d) = \frac{\exp.\ (\alpha d/d_{50c})-1}{\exp.(\alpha d/d_{50c})+\exp.(\alpha)-2} \times 100 \qquad (2.10)$$

The reduced efficiency curve may be considered as the key for prediction of cyclone performance and accurate selection of cyclone for any given application.

2.3.1 Estimation of d_{50}

A number of empirical expressions are available in literature to make an estimate for d_{50} for material as a function of cyclone design parameters and operating conditions. Moder and Dahlstrom[19] found the following expression for the design of large cyclones:

$$d_{50} = 81 \frac{(D_o . D_i)^{0.68}}{Q^{0.53}} [1.73/(\rho_S - \rho_L)]^{0.5} \qquad (2.11)$$

where d_{50} is in microns, ρ_S and ρ_L are specific gravities of solid and liquid respectively. This equation was further modified by Matschke and Dahlstrom[20] for small diameter cyclones (10-40 mm) as

$$d_{50} = 87.2 \frac{(D_o . D_i)^{0.65}}{Q^{0.60}} \left[\frac{1}{\rho_S - \rho_L}\right]^{0.5} \quad (2.12)$$

Yoshika and Hotta[13] developed an equation using the orbital concept and the equilibrium cone surface defined by the end of vortex finder and the cone apex.

$$d_{50} = 6.3 \times 10^6 \, (D_c)^{0.1} (D_i)^{0.6} (D_o)^{0.8} \left[\frac{\eta}{Q(\rho_S - \rho_L)}\right]^{0.5} \quad (2.13)$$

where D_c is cyclone dia. in meters, D_i and D_o are also in mts., Q is in litres/sec, ρ_S and ρ_L are in Kg/m^3 and η is fluid viscosity in Kg/msec.

It should be mentioned here that the d_{50} defined in above expressions refer to actual d_{50} (d_{50} obtained from actual efficiency curve) and not to corrected d_{50}.

An expression for corrected d_{50} has been proposed by Lynch and Rao[9] on the basis of experimental

data obtained by classification of silica and copper are in 20'' hydrocyclone.

$$\log \; d_{50c} = \frac{D_o}{2.6} - \frac{D_u}{3.5} + \frac{P}{10.7} - \frac{WOF}{52} + K_5 \qquad (2.14)$$

where D_u is diameter of spigot, WOF is water in overflow in tons/hour, and K_5 is a constant.

As it was mentioned in the beginning of this chapter, not much information is available in literature on the performance characteristics of compound washer cyclones. The above review is, therefore, restricted only to the performance characteristics of the hydrocyclone classifiers. In the present study an attempt has been made to verify whether similar equations can be used for compound washers and whenever possible to propose new equations.

CHAPTER 3

EQUIPMENT AND EXPERIMENTAL PROCEDURE

3.1 Test Circuit: A 3'' washer cyclone was arranged in a closed circuit with a sand pump via a cylindrical pulp tank. The circuit is shown in Fig. 3.1 and the design of the compound water cyclone is shown in Fig. 3.2. The pulp was driven by a 1/4 H.P., 1472 r.p.m. motor. Vary-pitch-pulley system was used to vary speed of the motor, and hence the throughput to the cyclone. An impeller placed vertically above the tank was driven by a 1/4 H.P., 2500 r.p.m. motor, was used to stir the pulp in order to ensure satisfactory suspension of solids. Vortex finders of diameters 11.10 mm, 12.90 mm and 19.32 mm and spigots of diameters 11.54 mm, 12.10 mm and 12.80 mm were used for the experimental runs.

The details of test circuit are as follows:

(1) The feed tank was steel fabricated, with a tappered bottom, and the inner walls were provided with baffles, made of steel plates. The outlet at the bottom of tank was connected to the sand pump by a rubber tubing arrangement to avoid the formation of any sharp angle in the line (which may cause settling of solids in the pulp) and also to provide flexibility to clean the line, whenever

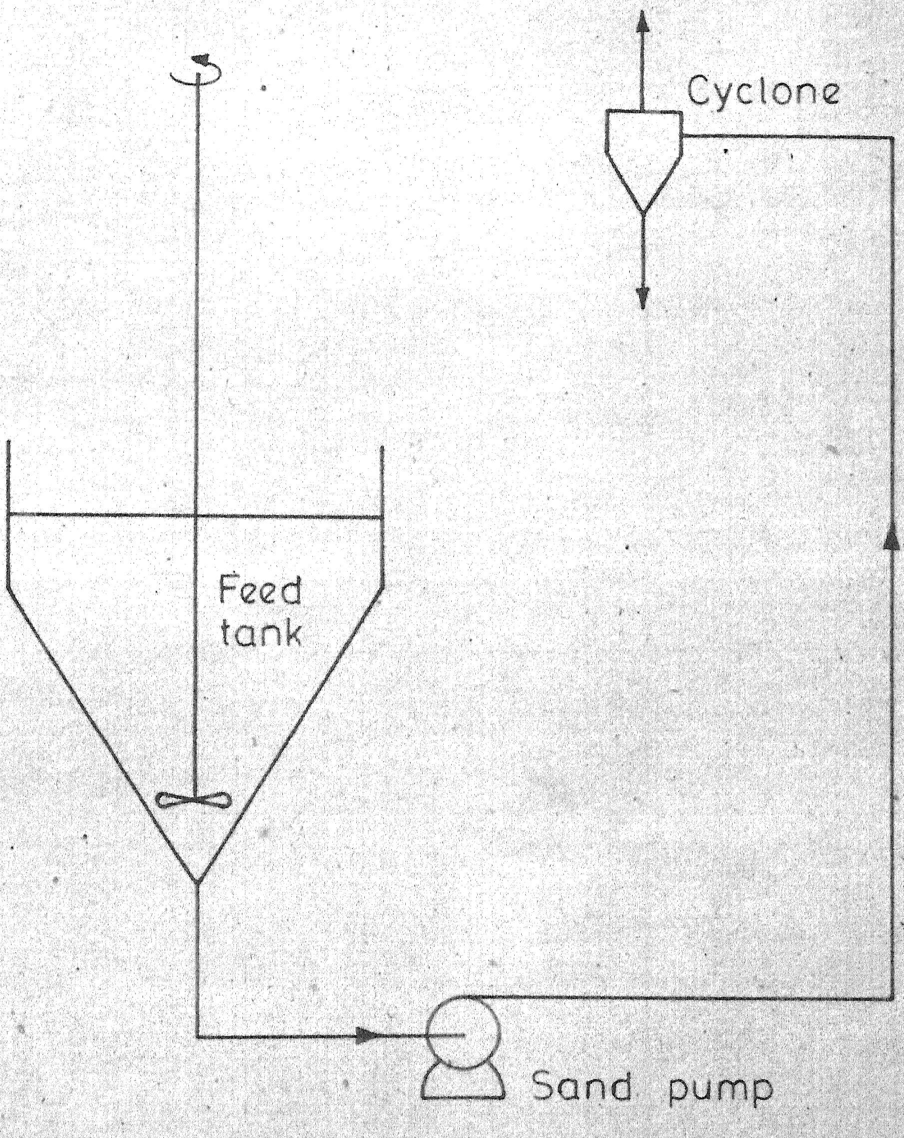

Fig. 3.1 - Schematic diagram of test rig.

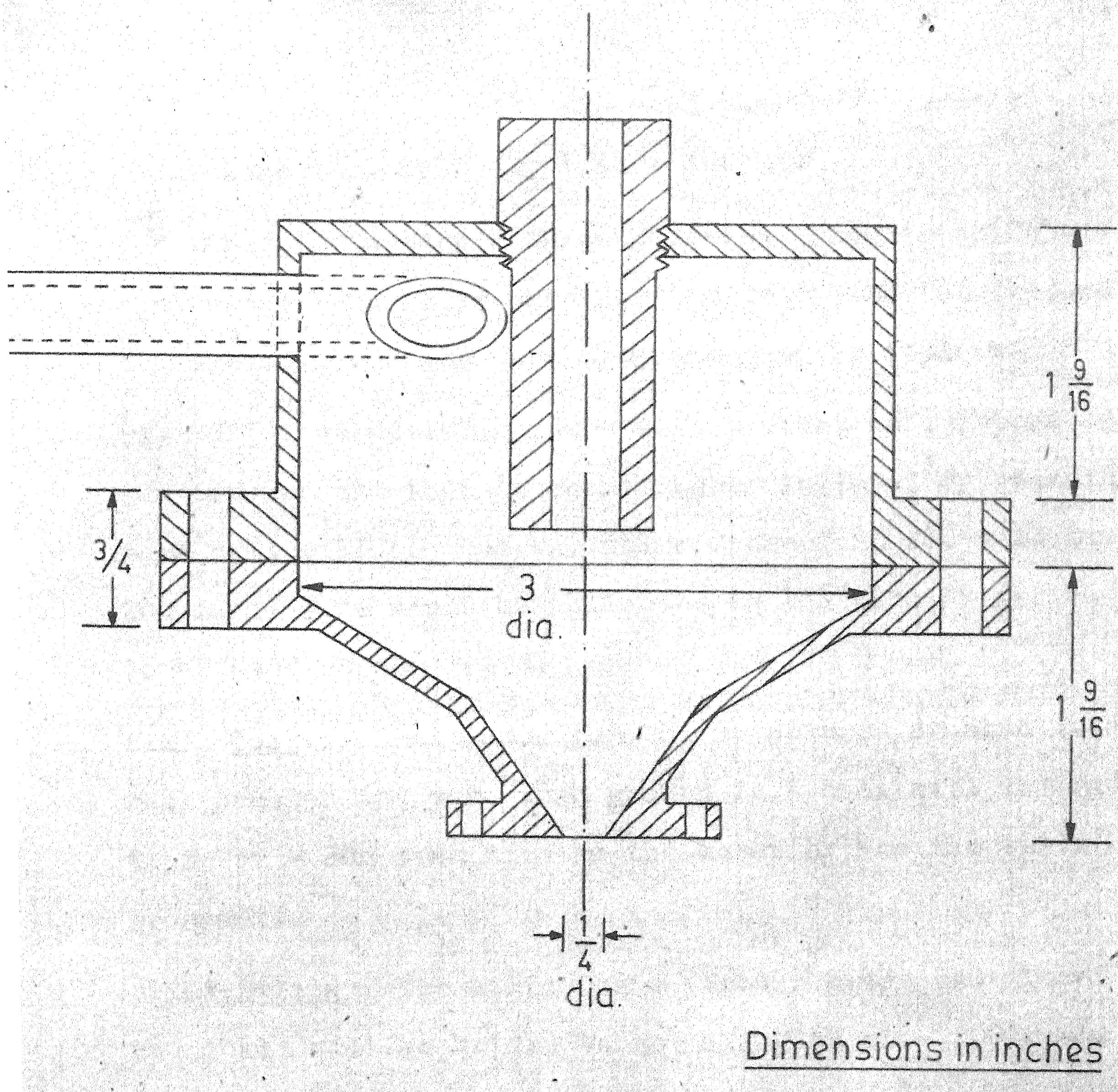

Fig. 3.2 - Basic design of experimental compound water cyclone 3" dia, 118° included angle.

necessity arises. (2) The sand pump was connected to cyclone feed inlet by rubber tubing.

3.2 Materials used: Three different materials (Calcite, coal and silica) were used for the tests and the preparation of materials for the test programme was as follows:

(i) Calcite: Calcite lumps were crushed in a laboratory jaw crusher and then in roll crusher followed by grinding in a ball mill so that particles finer than 200 mesh (i.e. 200 mesh) size could be collected as the final material to be used in the tests.

(ii) Coal: Coal lumps (sp.Gr. 1.45) were crushed in a roll crusher and were then ground in a ball mill to fractions of - 200 mesh size as the material for the tests programme.

(iii) Silica: The silica sand (Sp.Gr. 2.43) was ground in a ball mill as before to get material of - 200 mesh size for the tests.

3.3 Experimental Procedure: At the beginning of each test the desired vortex finder and spigot orifices were inserted into the cyclone. To start with adequate quantities of water and solids were fed into the feed tank and mixed thoroughly to get the desired percentage of solids in the feed pulp. The pulp was run through the cyclone

for sufficient length of time to ensure thorough dispersion of solids. Approximate feed density was measured by collecting samples in a calibrated bottle directly from the tank and the weight of the bottle was then compared with a previously calibrated chart to know the approximate specific gravity of the pulp. The pulp of same concentration were kept ready in another container and then poured in the feed tank to maintain flow rate constant during the experiment.

Changes in the feed pulp density was brought within required range by addition of either solid or water to the system. The system was allowed to run for a few minutes to reach equilibrium.

3.4 Collection of Samples: The steps followed in the collection of samples were as described below: (a) As soon as the feed pulp was fed into the cyclone, the excess of material prepared in the extra container was poured into the feed tank to make the level of pulp constant in the feed tank. Then the samples from overflow and underflow were collected in separate, previously weighed containers for fixed time interval. Each sample was weighed, and put back into the tank. The next sample was collected and the procedure was continued till the respective overflow and underflow masses showed no considerable differences

with the previous readings. This was done to ensure the attainment of steady state flow in the circuit. The final readings were used for flow rate calculations.

(b) After the steady state was reached, individual samples of overflow and underflow were also collected simultaneously for a fixed period of time for determining the efficiency of cyclone by sizing analysis.

3.5 Analysis of Samples: The samples collected were weighed, filtered and transfered to the previously weighed enamel trays for drying in an oven. The dried samples were weighed for density calculations. Then sampling of each sample was carried out by Andreasen Pipette Method.

For sizing analysis by Andreasen Pipette Method, the obtained sample was weighed out (5.5 gms for a 1 percent or 2 percent suspension by weight) and treated for dispersion in a small volume of water. The dispersion sample was then washed into the Andreasen Pipette and diluted exactly to the 20 cms. height (of the Andreasen Pipette). The exact volume to fill the cylinder to this point should be known so that the initial concentration 'C_0' may be calculated accurately. The apparatus was closed and inverted repeatedly with the air vent closed by a finger to obtain thorough mixing. The apparatus was then placed on a stationary, vibration free table.

To start with the experiment, a sample of suspension (10 cc by volume) was withdrawn after one minute, dried under standard conditions and weighed to the nearest 0.1 mg. At the same time the settling depth (which is decreasing after removal of each sample) was also recorded with data. Similarly, the readings were taken by withdrawing the samples periodically e.g. at 1,2,3,5,10,15,30 minutes.

The size analysis was carried only for calcite and silica and not for coal ~~because~~ coal was getting burnt during drying.

These readings could be converted to particle size by using the following formula,

$$D_t = 141 \left[\frac{1.h.\eta}{t(\rho_s - \rho_L)} \right]^{0.5} \qquad (3.1)$$

where D_t is in microns, t is the time at which the sample is collected in minutes, h is the depth below the surface at which the sample is collected in cms., η is the viscosity of the medium in poise, and ρ_s and ρ_L are the specific gravities of the solid and liquid respectively.

CHAPTER 4

RESULTS AND DISCUSSION

Experiments were carried out on three different materials, namely, calcite, coal and silica using vortex finder and spigot orifices of three different diameters each. The three vortex finders used were of 19.32 mm, 12.9 mm and 11.10 mm and spigot diameters were 12.80 mm, 12.10 mm and 11.54 mm. The samples of calcite, coal and silica were collected 5,7 and 5 seconds, respectively, after the steady state was achieved. The pulp densities for calcite, coal and silica were kept around 6 percent, 4 percent and 8 percent solids respectively in all the experiments. The collected samples were analysed for determination of flow rates of water and solids in overflow and underflow. At steady state flow rate of water in feed would be the sum of flow rates of water in overflow and underflow. Table 4.1 presents the analysis of samples for different vortex finder and spigot orifices for calcite. To check the reproducibility of the data, each experiment was repeated that is why in Table 4.1 for a given set of vortex finder and spigot two values of flow rates of water and solids in overflow and underflow have been reported. Similar results for coal and silica are presented in Table 4.2 and 4.3 respectively.

After drying, the overflow and underflow samples, calcite and silica samples were weighed and subjected to particle size analysis using Andreasen Pipette. The data was then used to evaluate actual and corrected efficiencies using equations (2.8) and (2.9), respectively. Table 4.4 to 4.11 present the size analysis and efficiencies values for calcite for different sets of vortex finder and spigot. Two values in each row correspond to two different experiments that were performed for each set of vortex finder and spigot. The results for the second experiment are indicated by a superscript asterisk(φ). Similar results for silica are reported in Tables 4.12 to 4.20. As the reproducibility of data was found to be quite satisfactory for calcite, it was thought unnecessary to repeat all the experiments for silica also. Therefore, only a few of them were repeated.

4.1 Throughput of Compound Washer

The effect of vortex finder and spigot diameter and material on cyclone throughput of compound washer has been investigated in the present study. An equation expressing throughput as a function of vortex finder, spigot, pressure, particle size has been proposed by Lynch and Rao for cyclone as classifier (Eq. 2.4). For the convenience the equation is reproduced below.

$$Q = 15.63\ (D_o)^{0.68} (D_u)^{0.16} (D_i)^{0.85} (P)^{0.49} (-53\ \mu)^{-0.35} \tag{4.1}$$

If one expects a similar type of behaviour for throughput of compound washer also, equation of following form should be valid.

$$Q = K(D_o)^{C_3}\ (D_u)^{C_4}\ (D_i)^{C_5} (P)^{C_6} (-53\ \mu)^{-0.35} \tag{4.2}$$

where K, C_3, C_4, C_5 and C_6 are constants.
Above equation can be rewritten as

$$\text{Log } Q = \text{Log } K + C_3 \log D_o + C_4 \log D_u + C_5 \log D_i + C_6 \log P - 0.35 \log(-53\ \mu) \tag{4.3}$$

If all the variables but vortex finders are kept constant a plot of log Q V_s log D_o should be a straight line with slope equal to C_3. Figs. 4.1 to 4.3 represent the plots of log Q V_s log D_o for three different spigots for calcite, coal and silica, respectively.

From these figures it is obvious that within the experimental error limits the plots are straight lines. The value of exponent C_3 was evaluated from the slopes of these straight lines and is found to be constant within a range (0.671 - 0.685). This implies that the exponent C_3 does not depend on size of the vortex finder and spigot, and the type of the material. The average

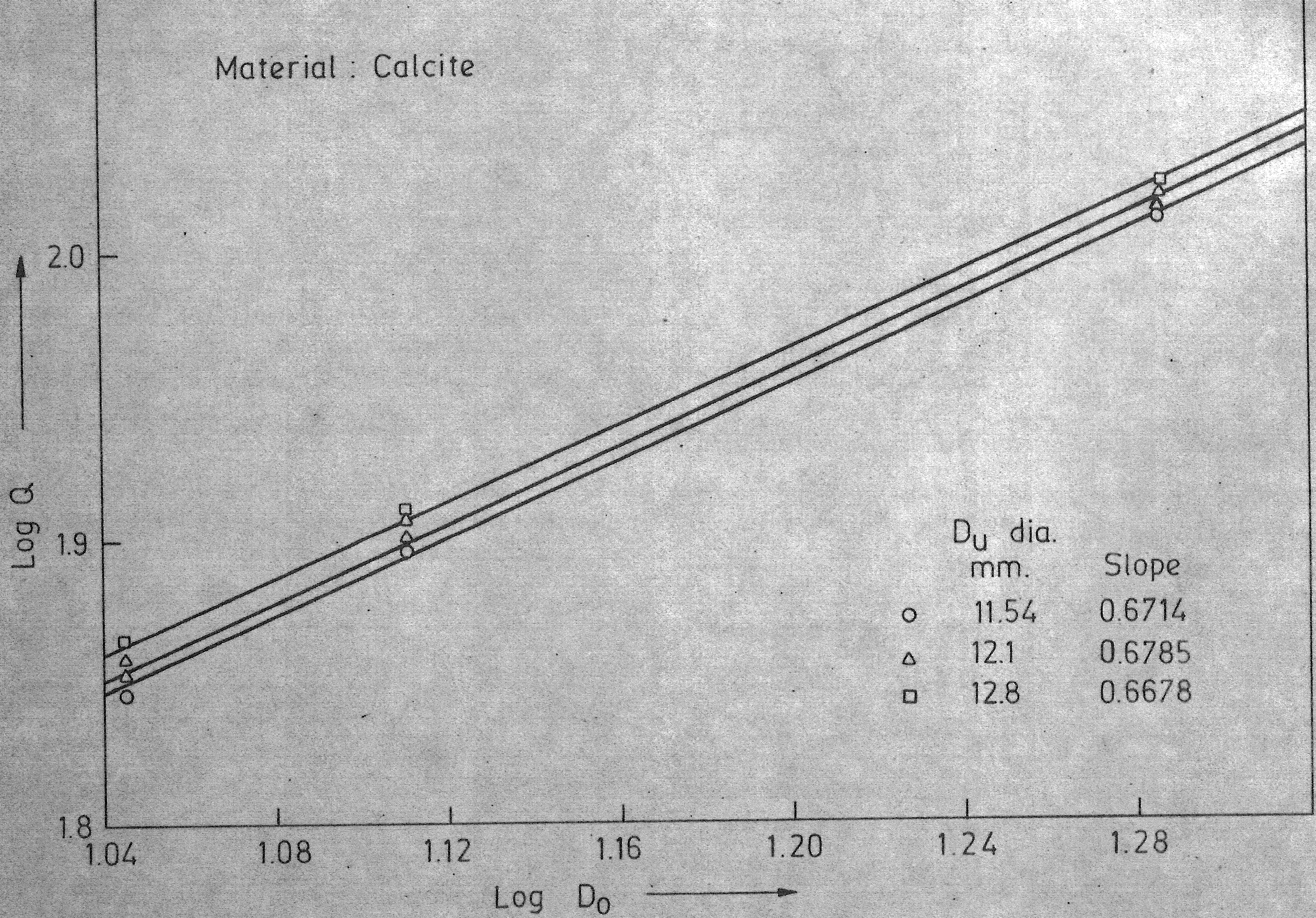

Fig. 4.1 - Graph of Q verses Do .

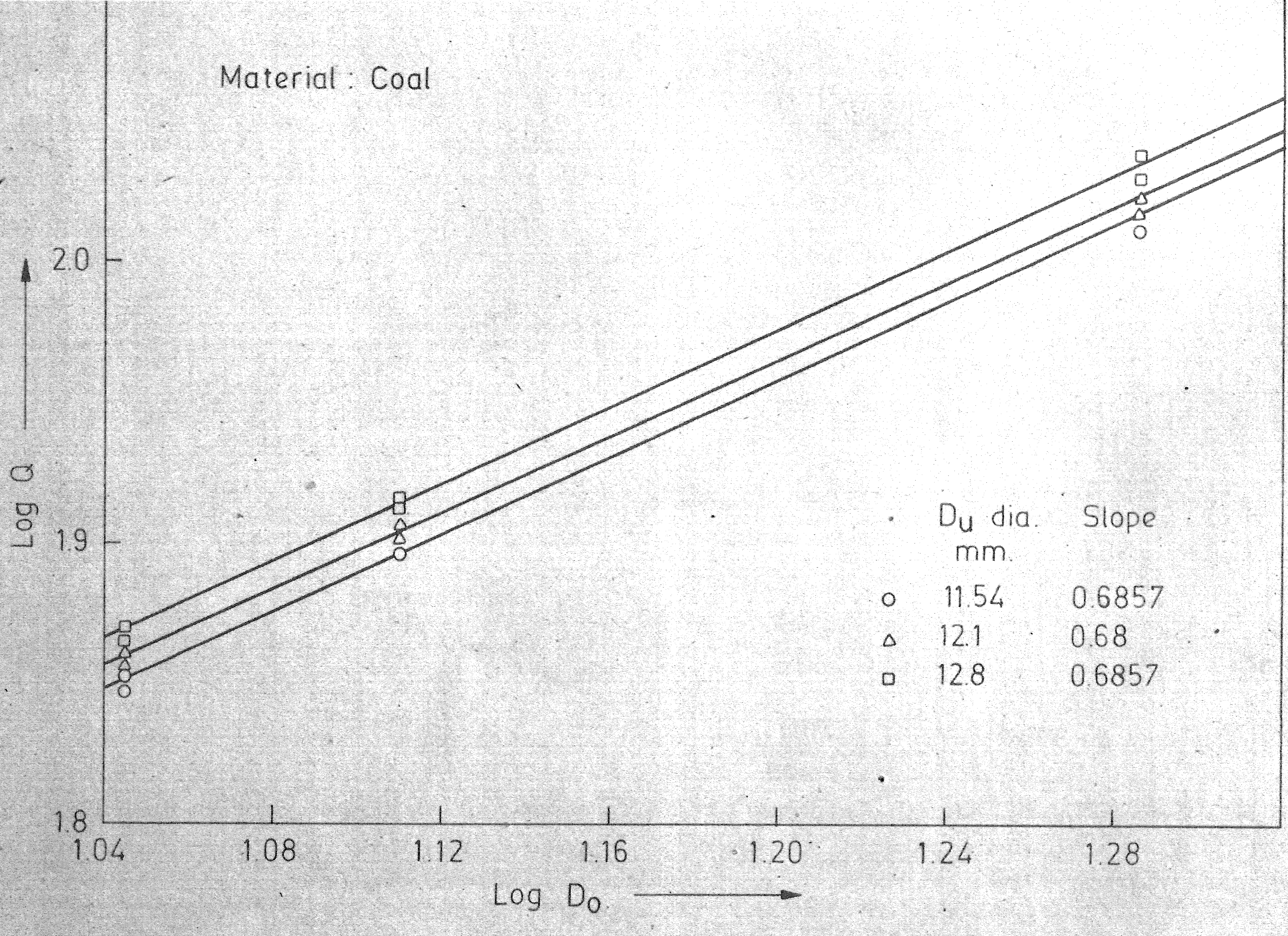

Fig. 4.2 - Graph of Q verses D_o . .

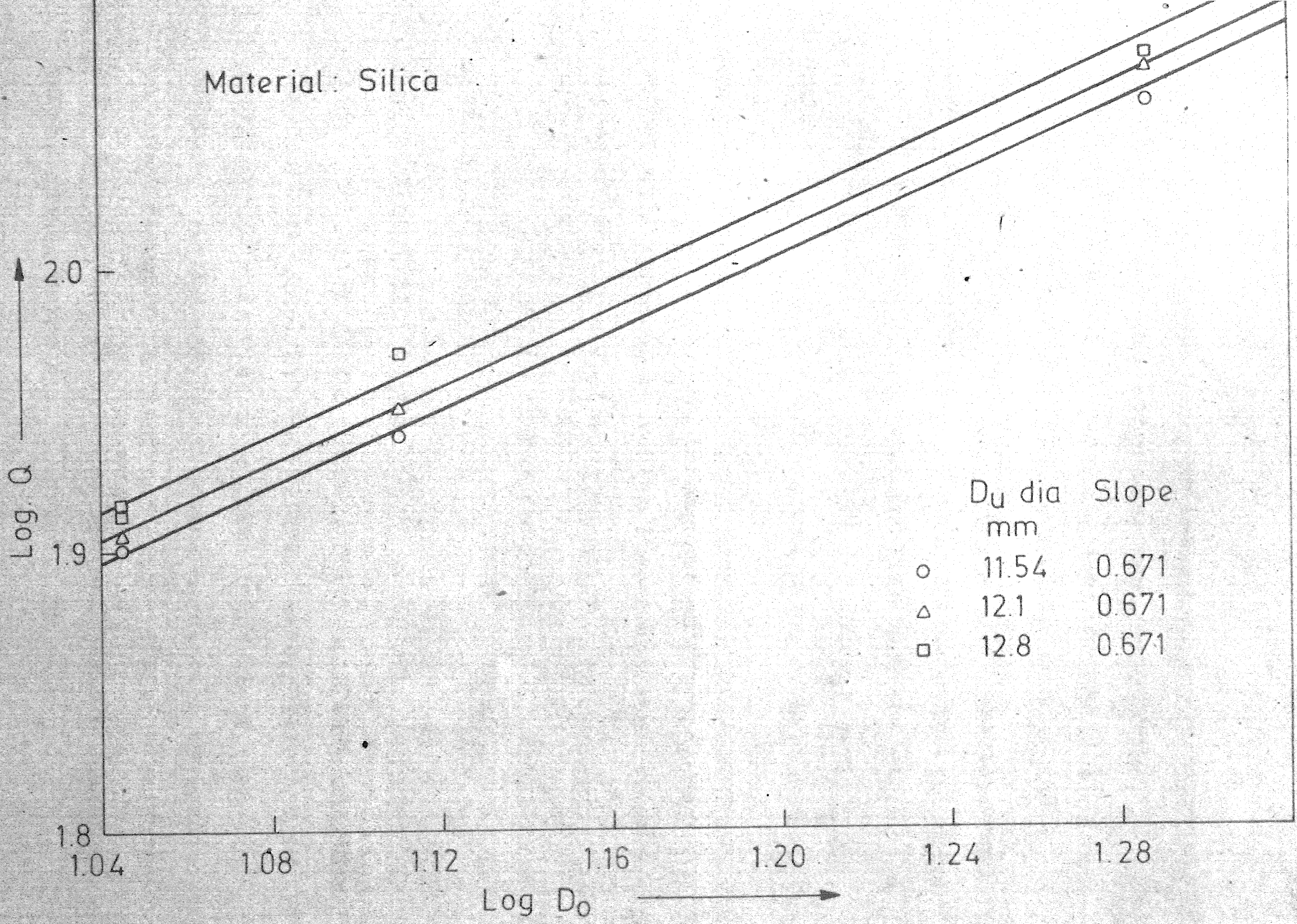

Fig. 4.3 - Graph of Q verses D_o

value of the exponent can be taken as 0.678. Similarly if all variables but spigot are kept constant a plot of log Q V_s log D_u should be a straight line with slop equal to C_4. Figs. 4.4 to 4.6 are the plots of log Q V_s log D_u for three different vortex finders for calcite, coal and silica, respectively. Within the experimental error limits these plots are straight lines and the slopes are constant within the range (0.20 - 0.28) supporting the validity of Eq. 2.4. The average value of exponent C_4 is 0.24.

Therefore, the throughput of the compound washer as a function of vortex finder and the spigot can be represented by the following equation

$$Q = K_6 \, (D_o)^{0.678} \, (D_u)^{0.24} \qquad (4.4)$$

where K_6 is a constant.

4.2 Water Distribution

Water distribution studies were made only for two materials, calcite and silica. Water collected in overflow and underflow in a fixed interval of time was weighed. Lynch and Rao proposed a relation between water in overflow, water in feed, and spigot diameter which is given by Equation (2.5). For convenience the equation is reproduced below

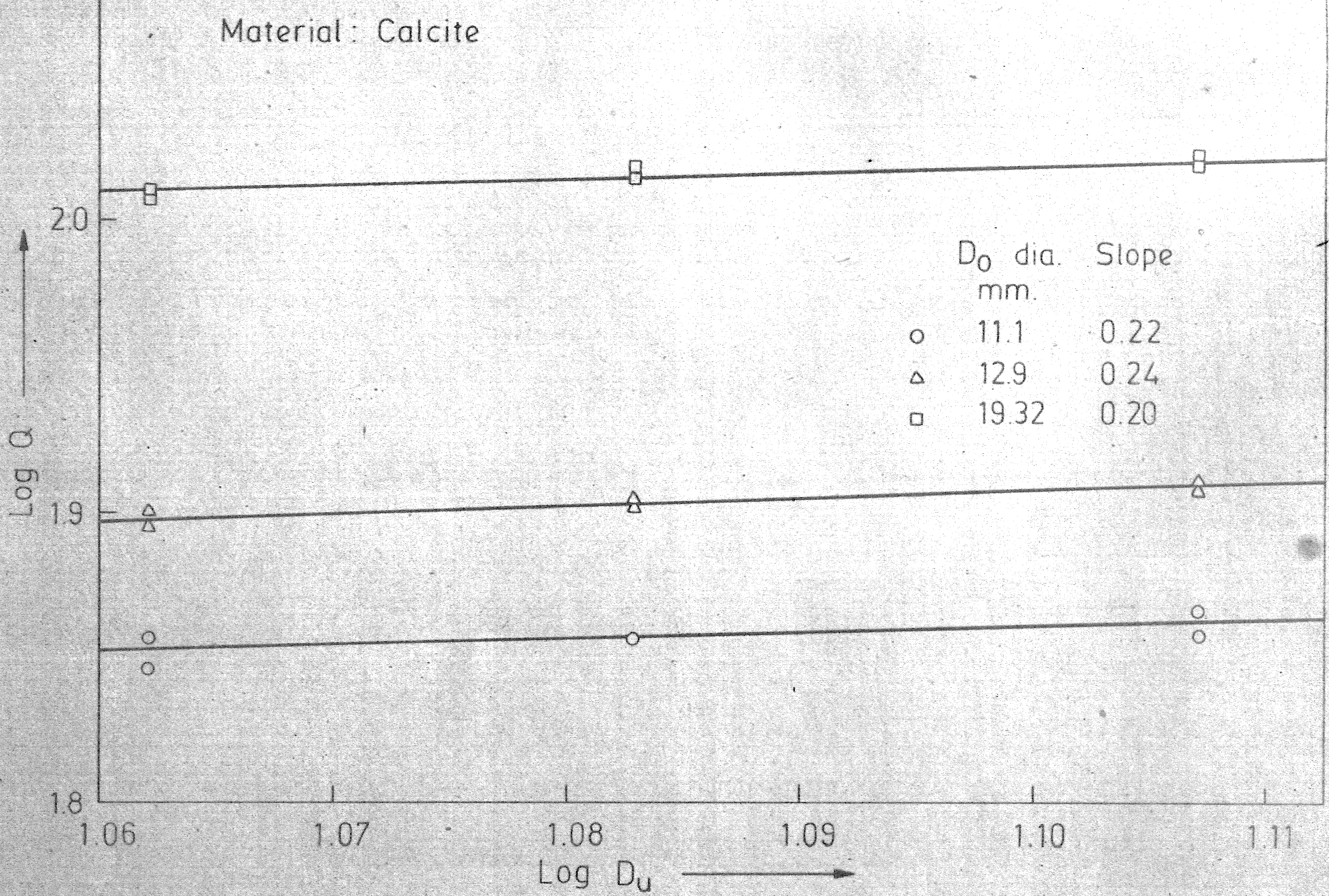

Fig. 4.4 - Graph of Q verses D_u

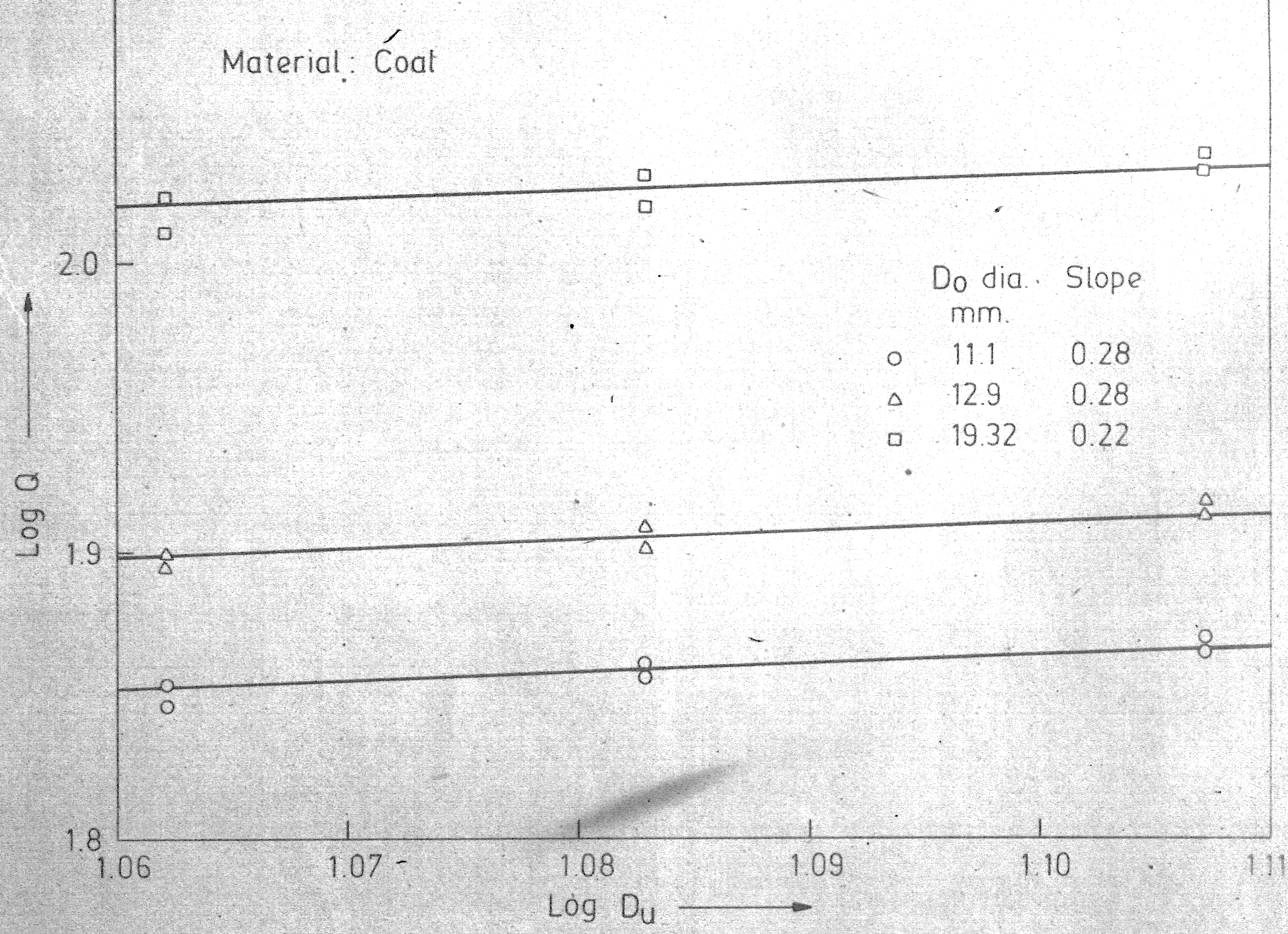

Fig. 4.5 - Graph of Q verses D_u.

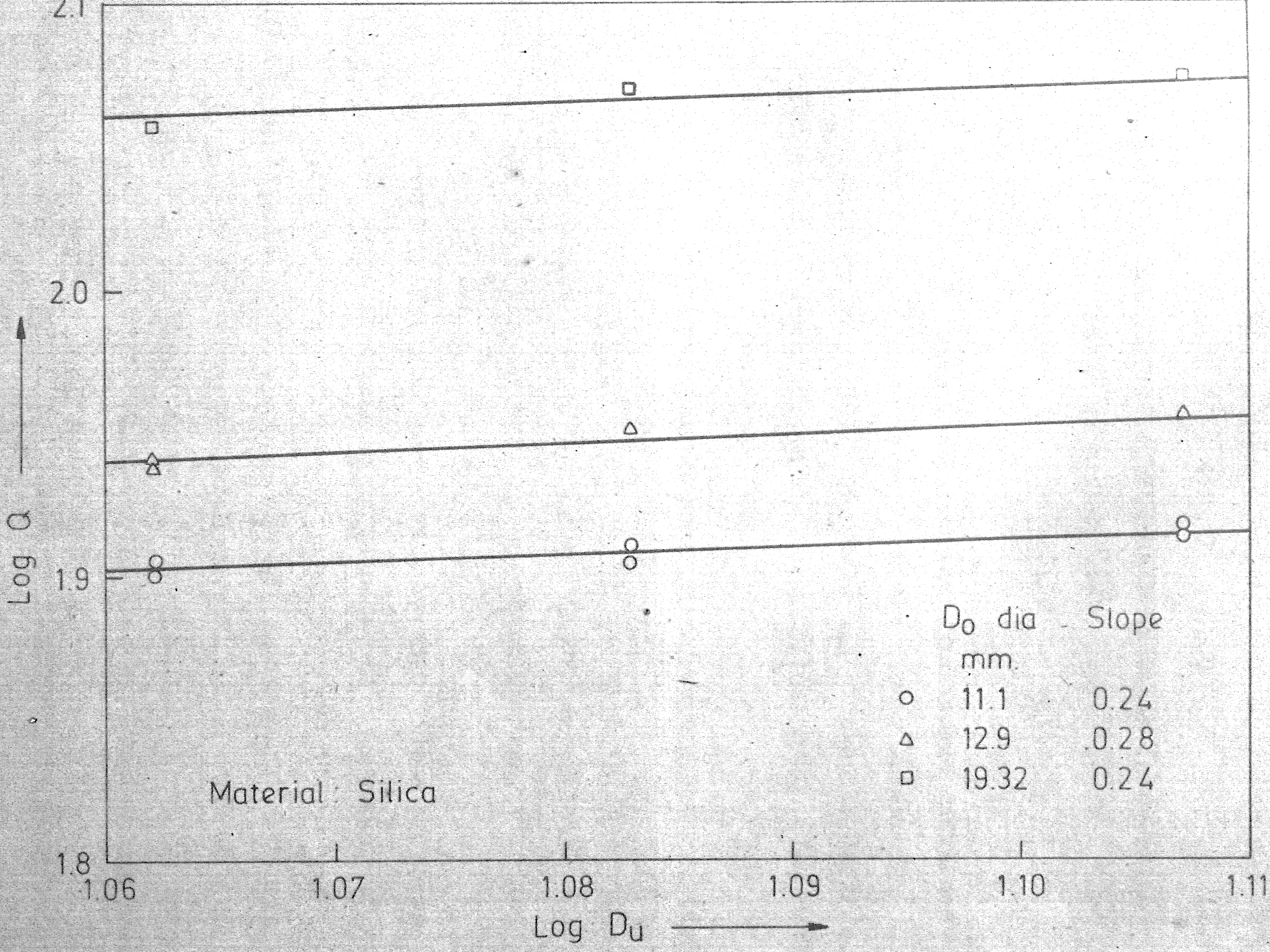

Fig. 4.6 - Graph of Q verses Du.

$$WOF = 1.06\ WF - 8.74\ D_u + 6.02 \qquad (4.5)$$

From this equation it is obvious that water in overflow should vary linearly as a function of water in feed for a given spigot diameter. To verify the validity of the above equation for a compound water cyclone plots of WOF Vs W_F were obtained for different spigots and different materials. But they did not exhibit linear behaviour expression by Eq. (4.5). The data was plotted in different forms and it was observed that the following equation matches well with the experimental data.

$$WOF = x_1 \log WF + C_7 \qquad (4.6)$$

where WOF is water in overflow, WF is water in feed and C_7 is constant. Plots of WOF and log WF for calcite and silica for different spigots are shown in Figs. (4.7 and 4.8) respectively. The value of the constant x_1 was estimated from the slopes of the straight lines in these figures. The constant x_1 is found to be independant of spigot diameter but varieswith materials. For calcite it was found to be 21.7 where as for silica it was 34.0 Constant C_7 depends on spigot diameter as well as on material. For calcite it was found to be 8.7 whereas for silica it was 26.48. We have not attempted to find this functional form for the lack of data.

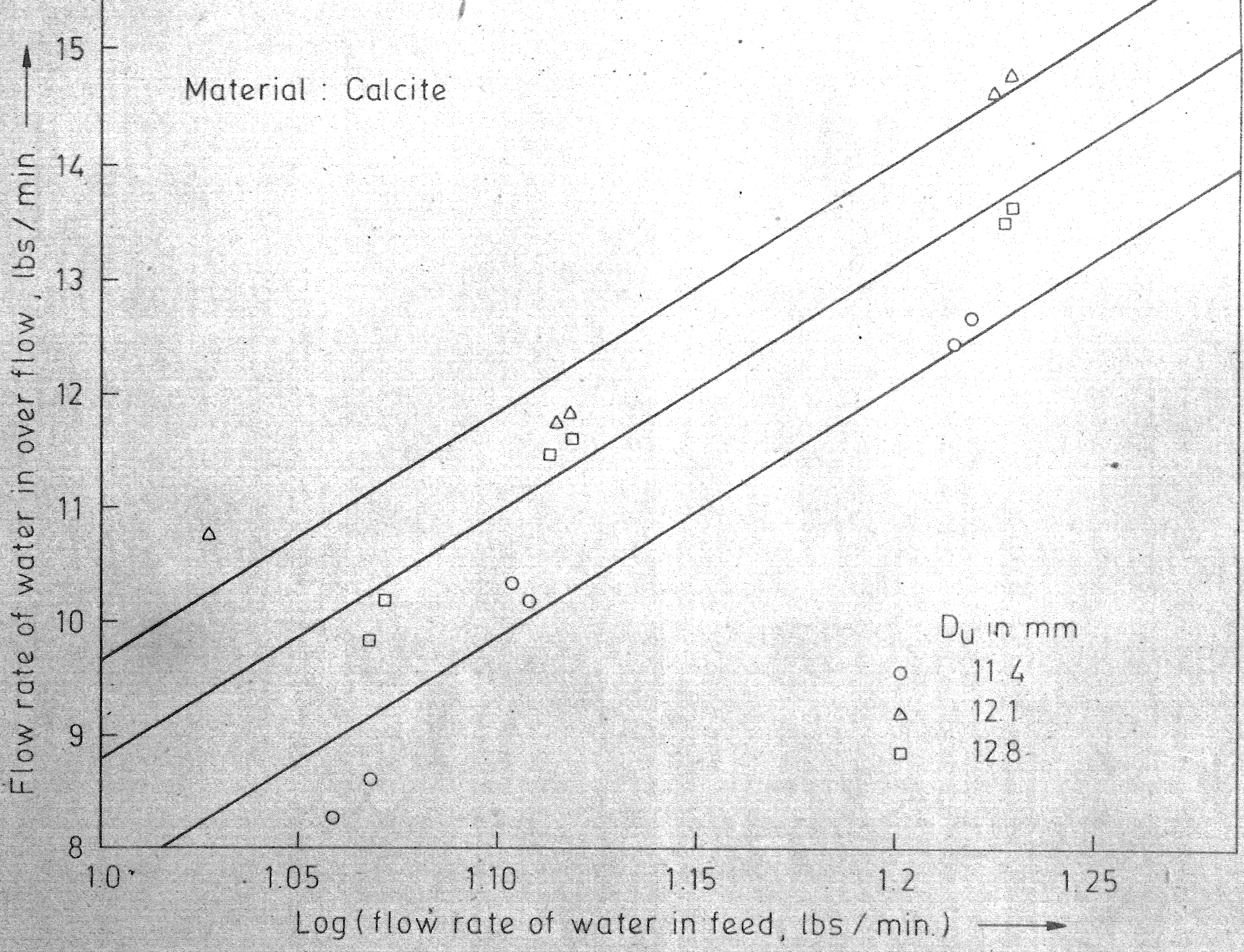

Fig. 4.7 - Relation between flow rate of water in feed and over flow.

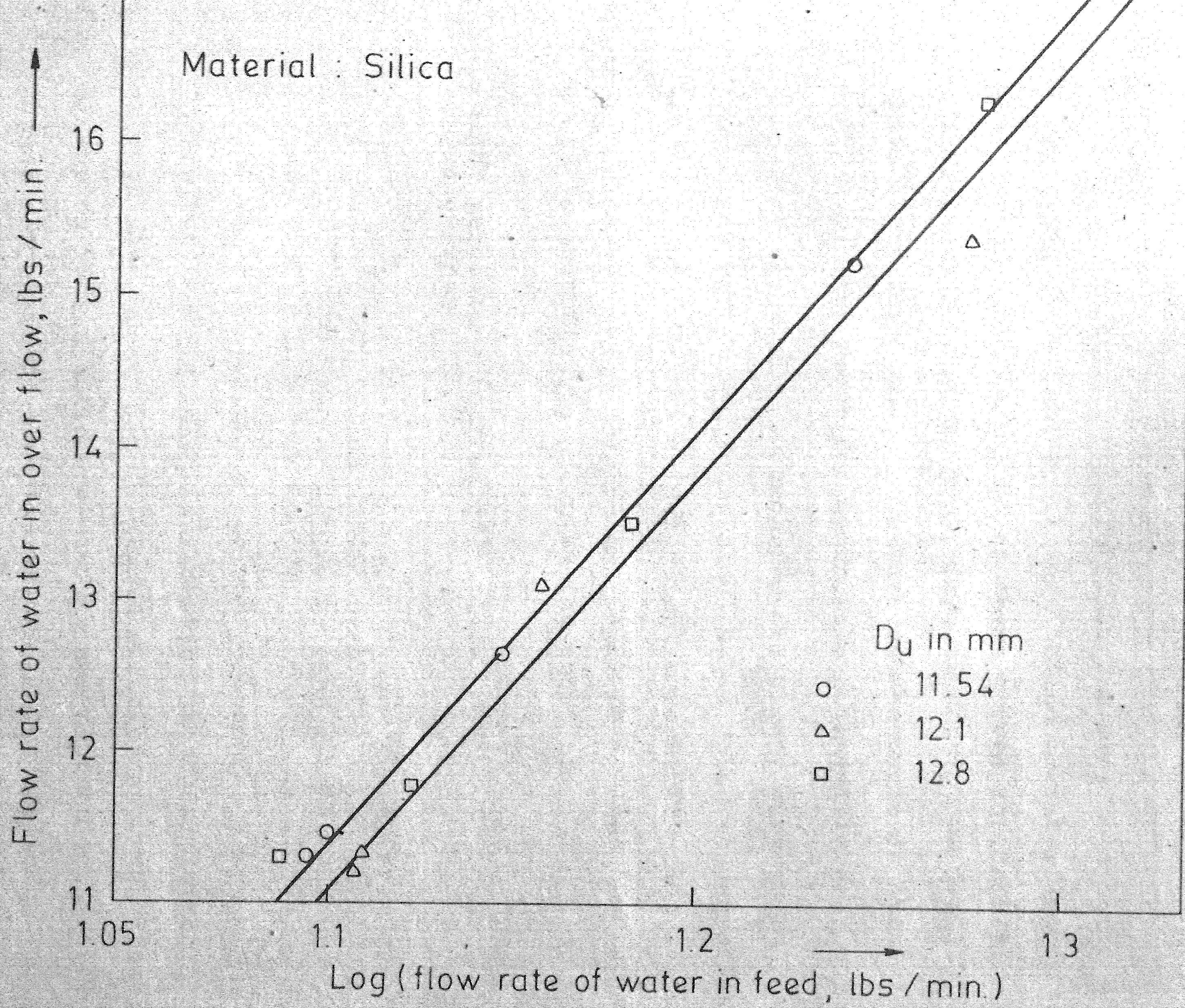

Fig. 4.8 - Relation between flow rate of water in feed and over flow

4.3 Efficiency Curves

The actual efficiency curves were obtained by plotting the weight percentage solids to underflow vs size of the particle. Some of these curves for calcite and silica are shown in Figs. (4.9 to 4.12). From these plots it is found that the nature of the curve is almost similar to that found for hydrocyclone classifiers.

To plot the corrected efficiency curves the weight percentage (corrected) solid going to underflow was obtained from the actual weight percentage solid going to underflow. Mathematically, weight percentage (corrected) solid to underflow is given by the equation

$$\text{Weight percentage (corrected) solids to underflow} = \frac{\text{Actual weight percentage of solids going to underflow} - R_f^{*}\text{(from graph)}}{1 - R_f\text{(from graph)}}$$

These values of weight percentages (corrected) solids going to underflow are then plotted against size to get the corrected efficiency curve. Some of the corrected efficiency curves are plotted (Figs. 4.9 to 4.12). It is found that the nature of the corrected efficiency curves **is also** similar to such curves for hydrocyclone classifiers.

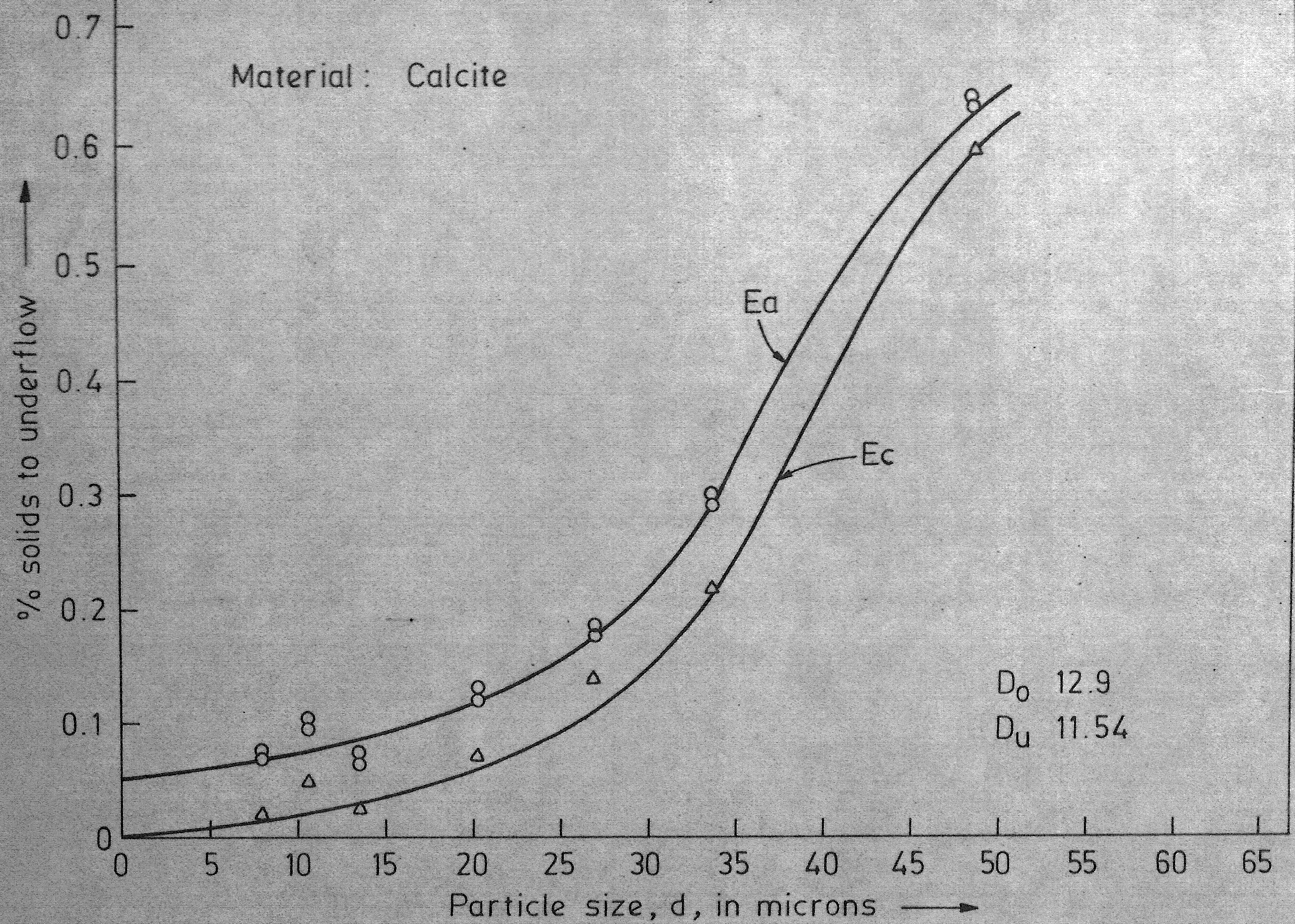

Fig. 4.9 - Actual and corrected efficiency curves.

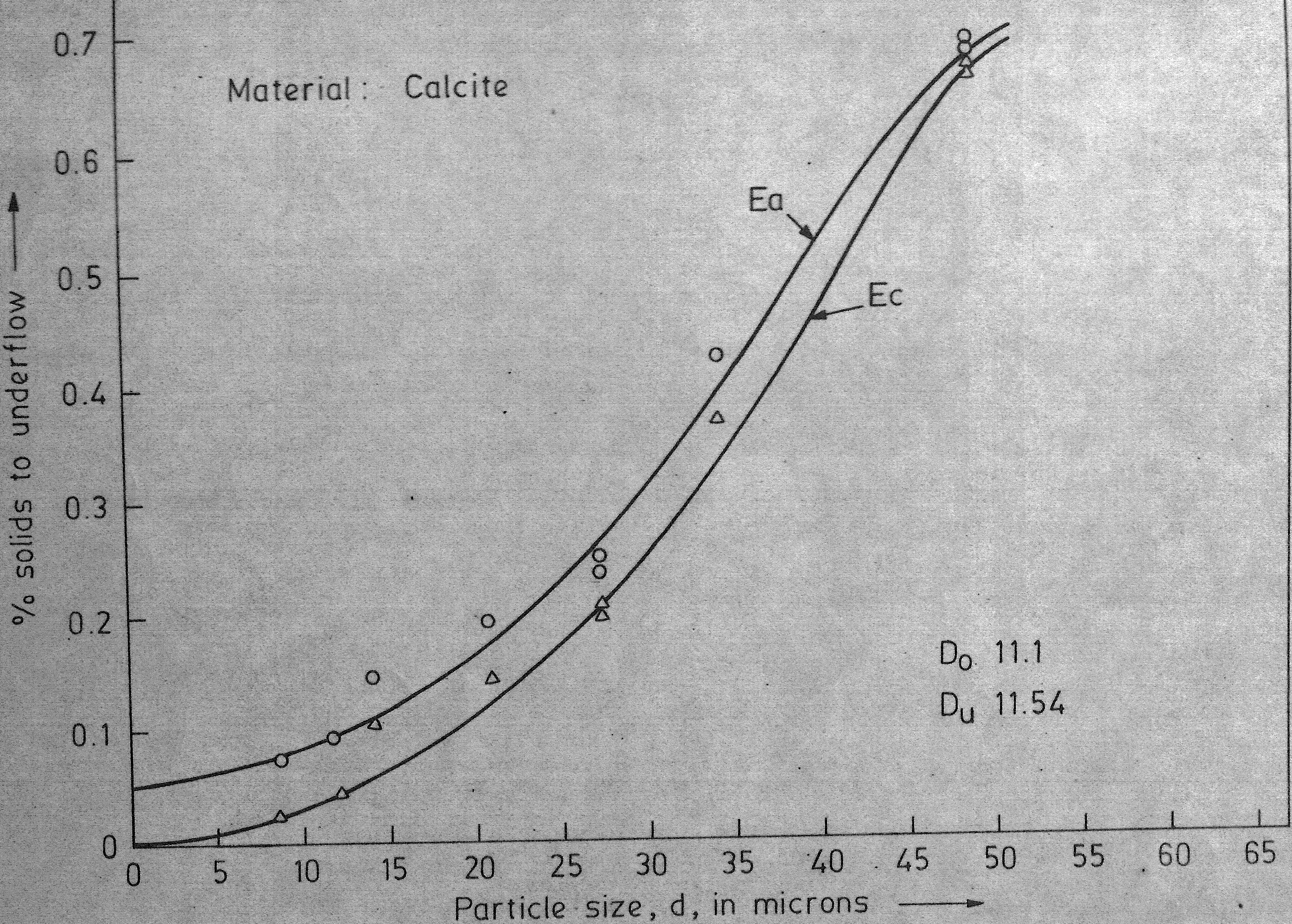

Fig. 4.10 - Actual and corrected efficiency curves.

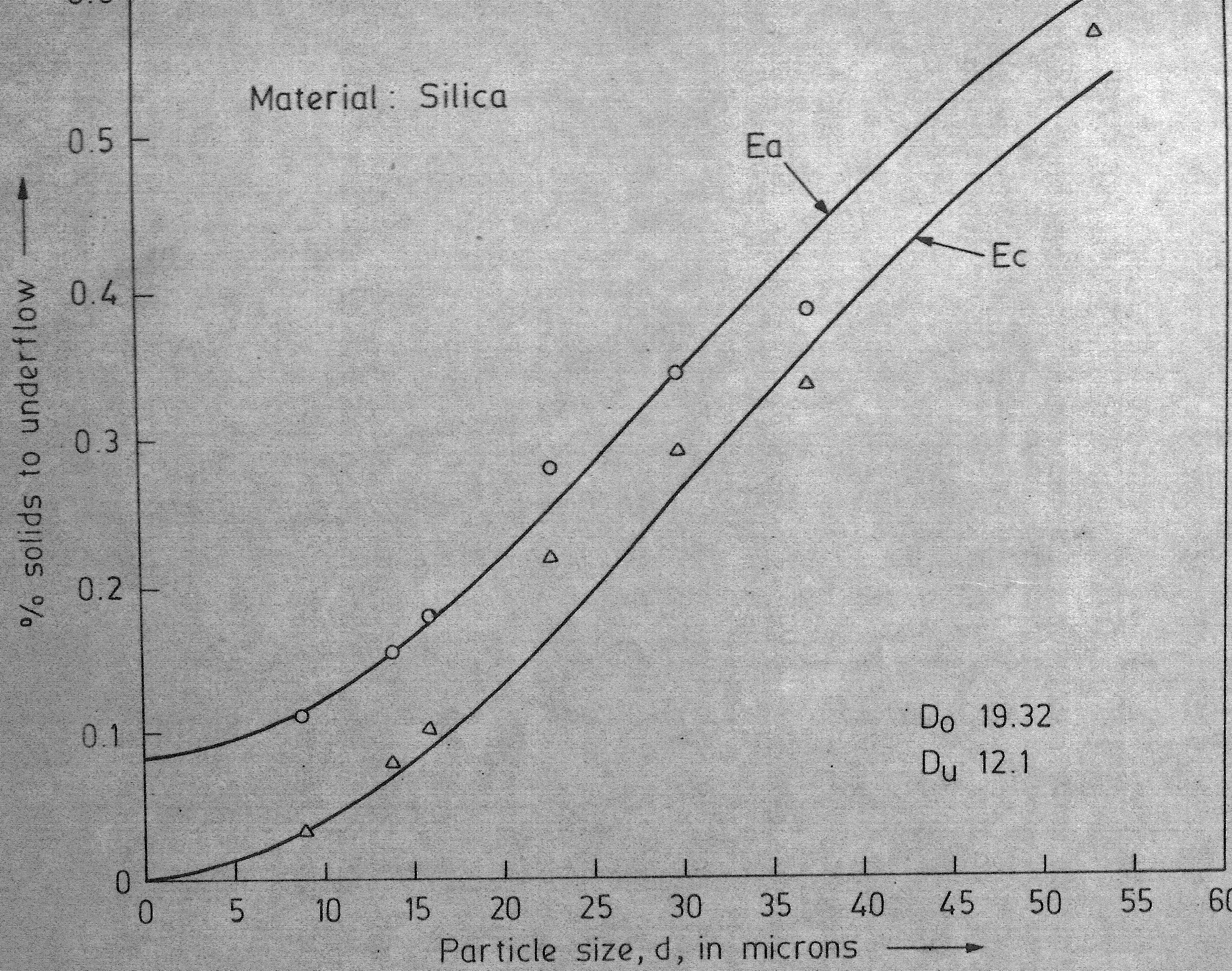

Fig. 4.11- Actual and corrected efficiency curves.

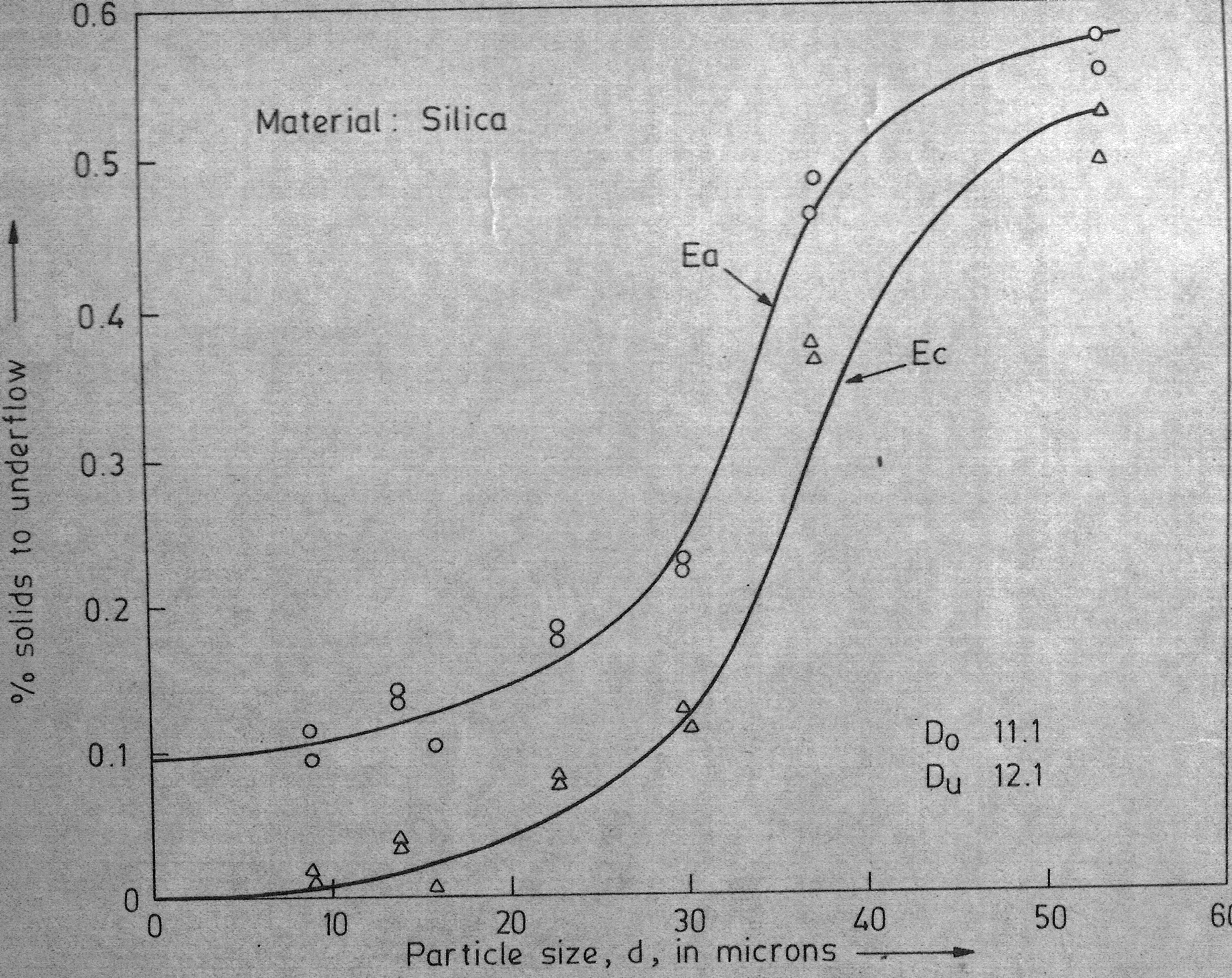

Fig. 4.12- Actual and corrected efficiency curves.

Reduced efficiency curves were then obtained for calcite and silica by plotting weight percentage (corrected) solids appearing in underflow vs. the size of particles divided by d_{50c}. The data points for both calcite and silica seem to fall on the same curve as shown in Figs. 4.13. and 4. Specific gravity of the material does not have any significant effect on the reduced efficiency curve.

Since the nature of actual, corrected and reduced efficiency curves for compound water cyclone are found to be similar to that of hydrocyclone classifiers, the efficiency equations which are valid for hydrocyclone classifiers can also be applicable to the compound water cyclones.

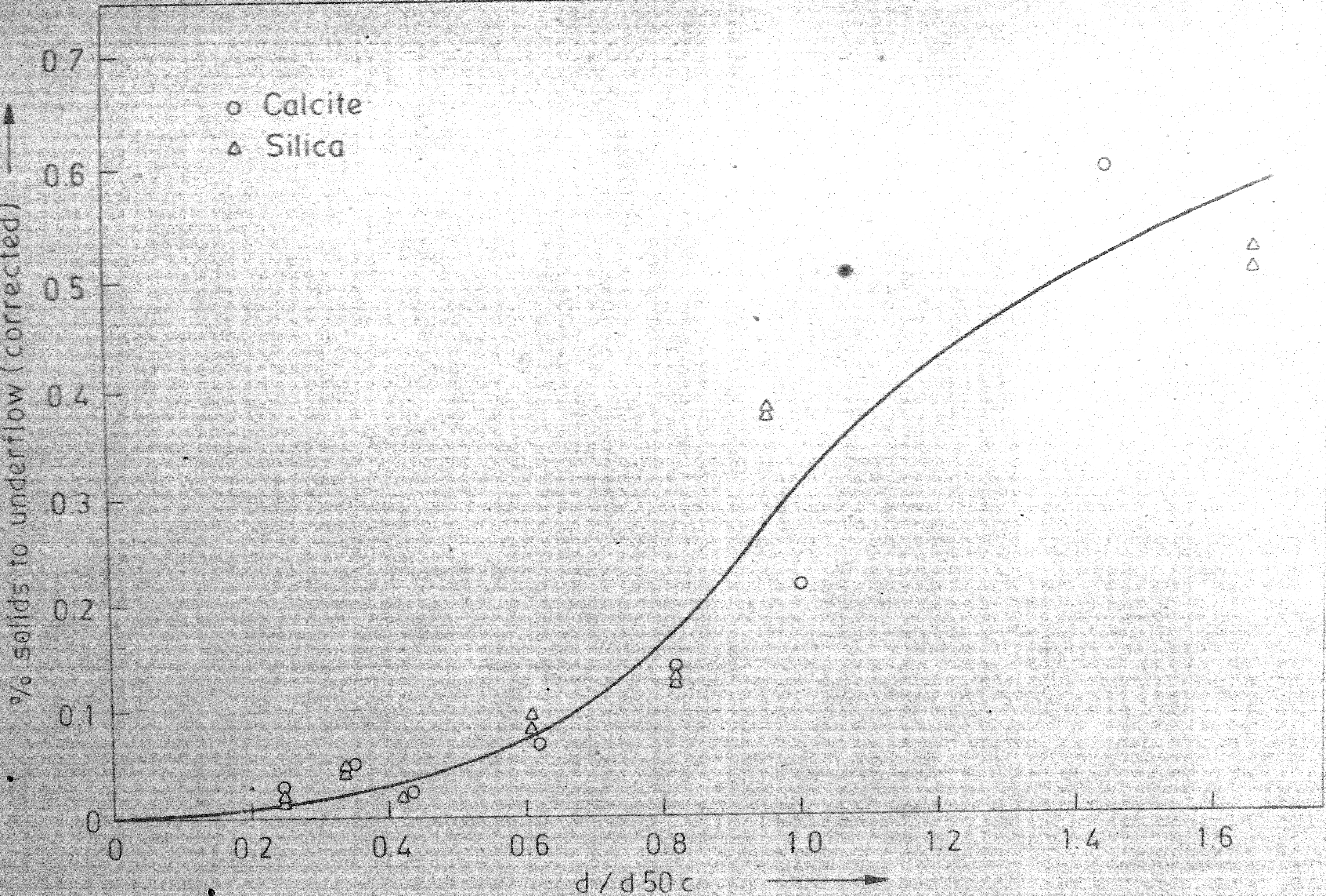

Fig. 4.13 - Reduced efficiency curve.

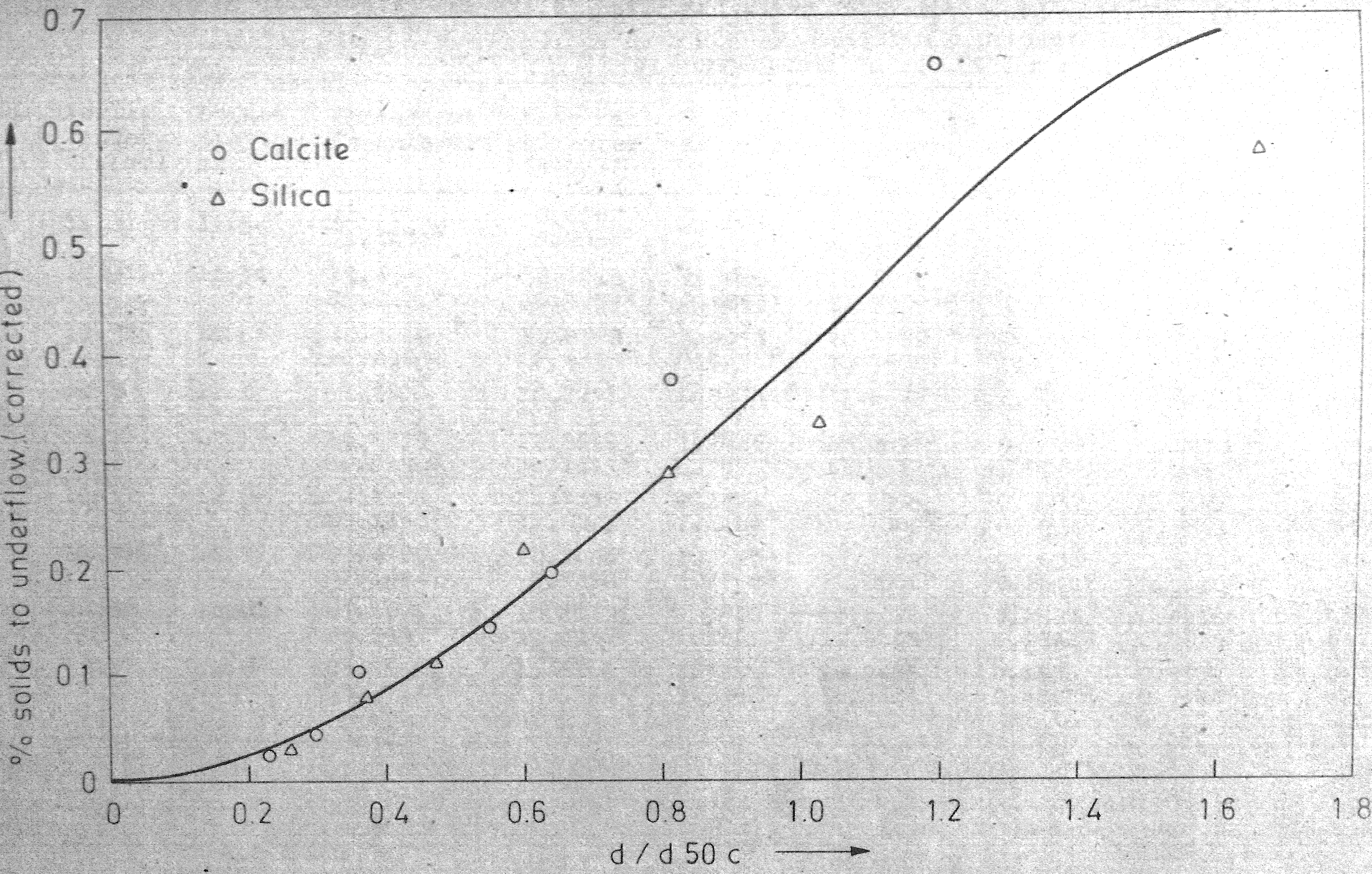

Fig. 4.14 - Reduced efficiency curve.

TABLE 4.1

Flow rate analysis of Solid and Water in overflow and underflow for Calcite
Pulp Density = 6 percent Solids
(φ corresponds to result for second set)

S. No.	Vortex finder dia(mm)	Spigot dia in mm	Throughput in gals/min	Flow rate of water in O/F	Flow rate of water in u/F	Flow rate of water in feed	Flow rate of solid in o/F	Flow rate of solid in u/F	Flow r[ate of] solid feed
1	11.10	11.54	71.78 71.4433φ	8.6169 8.2884φ	3.1857 3.1706φ	11.7026 11.4590φ	0.3651 0.3730φ	0.5706 0.5820φ	0.9360 0.9550
2	12.90	11.54	79.4300 79.822 φ	10.1918 10.3439φ	2.5000 2.4863φ	12.6918 12.8307φ	0.4167 0.4365φ	0.5952 0.5556φ	1.0119 0.9921
3	19.32	11.54	102.3040 101.2969φ	12.6328 12.4339φ	3.9253 3.9431φ	16.5582 16.3770φ	0.4598 0.4762φ	0.5045 0.5278φ	0.9643 1.0040
4.	11.10	12.10	71.3000	10.7791	0.8888	11.6679	0.0999	0.361	0.4609
5	12.90	12.10	80.6515 80.3390φ	11.8108 11.7619φ	1.2726 1.2698φ	13.0835 13.0317φ	0.2328 0.2302φ	0.4470 0.4497φ	0.6798 0.6799
6	19.32	12.10	104.1139 103.1440φ	14.7513 14.6243φ	2.1444 2.1124φ	16.8958 16.7368φ	0.2937 0.2910φ	0.5672 0.5661φ	0.8608 0.8571
7	11.10	12.80	73.4805 72.1684φ	10.1066 o.8280φ	1.7123 1.7786φ	11.8189 11.6066φ	0.2638 0.2646φ	0.6290 0.6156φ	0.8927 0.8802
8	12.90	12.80	81.4676 80.5993φ	11.6032 11.4947φ	1.5040 1.4661 φ	13.1071 12.9608φ	0.2884 0.2844φ	0.6918 0.7032φ	0.9802 0.9876
9	19.32	12.80	104.7655 104.2714φ	13.6169 13.5344φ	3.3286 3.3280φ	16.9455 16.8624φ	0.4836 0.4868φ	0.5339 0.5344φ	1.0175 1.0212

TABLE 4.2

Flow rate Analysis of Solid and Water in overflow and underflow for coal

Pulp Density = 4 percent solid
(φ corresponds to results for second set)

No.	Vortex Finder dia(mm)	Spigot dia in mm	Throughput in gals/min	Flow rate of water in o/F	Flow rate of water in u/F	Flow rate of water in feed	Flow rate of solid in o/F	Flow rate of water in u/F	Flow rate of solid in feed
1.	11.10	11.54	71.30 70.01 φ	10.2222 9.9674 φ	1.0862 1.2802 φ	11.3084 11.2476 φ	0.4165 0.2934 φ	0.2366 0.1181 φ	0.6531 0.4115 φ
2.	12.90	11.54	78.40 79.42 φ	11.3353 11.7078 φ	1.2238 1.1626 φ	12.5591 12.8704 φ	0.3843 0.4804 φ	0.1368 0.1790 φ	0.5210 0.6595 φ
3.	19.32	11.54	102.8 105.20 φ	13.0397 13.7377 φ	3.6037 3.3945 φ	16.6435 17.1322 φ	0.3575 0.4535 φ	0.1378 0.1250 φ	0.4956 0.5785 φ
4.	11.10	12.10	72.50 71.76 φ	10.0482 10.0203 φ	1.5495 1.3773 φ	11.5977 11.3976 φ	0.4658 0.3623 φ	0.1512 0.1533 φ	0.6170 0.5156 φ
5.	12.90	12.10	79.45 80.85 φ	11.5265 11.9268 φ	1.1442 1.0612 φ	12.6706 12.9879 φ	0.5295 0.4315 φ	0.1172 0.1104 φ	0.6466 0.5419 φ
6.	19.32	12.10	104.20 107.0 φ	13.0588 13.5537 φ	3.7343 3.5702 φ	16.7932 17.1239 φ	0.4521 0.6376 φ	0.1584 0.1524 φ	0.6105 0.7900 φ
7.	11.10	12.80	73.14 73.99 φ	10.1227 10.3645 φ	1.4232 1.4923 φ	11.5459 11.8568 φ	0.6331 0.2647 φ	0.1358 0.1139 φ	0.7689 0.3787 φ
8.	12.90	12.80	82.47 81.64 φ	12.0087 11.7459 φ	1.3303 1.4065 φ	13.3390 13.1524 φ	0.3723 0.4140 φ	0.1058 0.0769 φ	0.4781 0.4909 φ
9.	19.32	12.80	108.60 107.30 φ	14.6980 11.9803 φ	2.7998 2.5707 φ	17.4978 14.5510 φ	0.6019 0.4157 φ	0.2425 0.1362 φ	0.8444 0.5520 φ

Flow rate Analysis of Solid and Water in overflow and underflow for Silica

Pulp Density = 8 percent solid
(φ corresponds to results for second set)

Vortex finder dia(mm)	Spigot dia in mm	Throughput in gals/min	Flow rate of water in o/F	Flow rate of water in u/F	Flow rate of water in feed	Flow rate of solid in o/F	Flow rate of solid in u/F	Flow rate of solid in feed
11.1	11.54	79.5379	11.3242	1.1005	12.4247	0.3321	0.5794	0.9615
		80.3600 φ	11.4520 φ	1.1220 φ	12.5740 φ	0.4340 φ	0.6028 φ	1.0368 φ
12.9	11.54	87.1400	12.6339	1.3376	14.0265	0.3836	0.5437	0.9272
19.32	11.54	113.9038	15.2949	2.9828	18.2777	0.5649	0.7870	1.3519
11.10	12.10	80.7134 79.8000 φ	11.2791 11.3220 φ	1.5291 0.8690 φ	12.8082 12.1910 φ	0.5066 0.3840 φ	0.7989 0.5600 φ	1.3056 0.9440 φ
12.90	12.10	89.6762	13.2534	1.0463	14.2997	0.3709	0.9114	1.2823
19.32	12.10	117.2854	15.3915	3.4021	18.7937	0.5291	0.9259	1.4550
11.10	12.80	82.4027 82.0600 φ	11.7698 11.2998 φ	1.2817 0.9287 φ	13.0516 12.2285 φ	0.5347 0.4952 φ	0.8082 0.7850 φ	1.3920 1.2802 φ
12.90	12.80	90.3045	13.5066	1.0437	14.5503	0.4352	0.4907	0.9259
19.32	12.80	118.0639	16.2050	2.7593	18.9643	0.5939	0.7593	1.3532

TABLE 4.4

Material-Calcite

$D_o = 11.1$ mm, $D_u = 11.54$ mm

Set 1

1. Weight of Solids in O/F = 13.80 gms
2. Weight of Solids in U/F = 21.58 gms

Weight Solids in feed = 7.7 percent

Set 2

1. Weight of Solids in O/F = 14.10 gms
2. Weight of Solids in U/F = 22.00 gms

weight Solids in feed= 7.9 percent

(φ corresponds to results for second set)

ize n μ	Wt. of solids in U/F (gms)	Wt. of solids in O/F (gms)	Wt.% solids going to U/F	Wt.% solids going to O/F	Feed (gms)	E_a	E_c
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
.36	0.0620 0.0610φ	0.0644 0.0650φ	0.6876 0.6759φ	0.4567 0.4616φ	1.1443 1.1375φ	60.09 59.42φ	44.26 43.87φ
.76	0.0383 0.0380φ	0.0525 0.0515φ	0.4247 0.4211φ	0.3723 0.3657φ	0.7971 0.7868φ	53.29 53.52φ	34.76 35.71φ
.21	0.0212 0.0222φ	0.0222 0.0229φ	0.2351 0.2460φ	0.1574 0.1626φ	0.3925 0.4086φ	59.89 60.20φ	43.98 44.95φ
.80	0.0176 0.0175φ	0.0276 0.0274φ	0.1952 0.1939φ	0.1956 0.1850φ	0.3908 0.3789φ	50.12 51.10φ	30.30 32.39φ
.61	0.0134 0.0140φ	0.0238 0.0272φ	0.1486 0.1485φ	0.1684 0.1934φ	0.3170 0.3419φ	45.65 43.25φ	24.10 21.58φ
1.68	0.0089 0.0075φ	0.0216 0.0210φ	0.0987 0.0831φ	0.1432 0.2326φ	0.2419 0.2012φ	40.90 35.81φ	17.45 10.35φ
3.88	0.0067 0.0069φ	0.0190 0.0209φ	0.0743 0.0765φ	0.1347 0.1505φ	0.2090 0.2270φ	35.5 33.76φ	2.39 2.22φ

TABLE 4.5

Material-Calcite

$D_o = 12.9$ mm, $D_u = 11.54$ mm

Set 1

1. Wt. of Solids in O/F = 16.5 gms
2. Wt. of Solids in U/F = 21.0 gms
   Percentage of solids in feed = 7.5 percent

Set 2

1. Wt. of Solids in O/F = 15.75 gms
2. Wt. of solids in U/F = 22.50 gms
   percentage of solids in feed 7.5 percent

(φ corresponds to results for second set)

...ze μ	Wt. of solids in U/F (gms)	Wt. of solids in O/F (gms)	Wt. % solids going in U/F	Wt. % solids going in O/F	Feed (gms)	E_a	E_c
)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
...56	0.0609 0.0600φ	0.0527 0.0730φ	0.6201 0.6417φ	0.4335 0.5465φ	1.0536 1.1882φ	58.85 54.01φ	48.95 42.72φ
...76	0.0283 0.0285φ	0.0356 0.0361φ	0.2902 0.3048φ	0.2848 0.2703φ	0.5750 0.5751φ	50.47 53.00φ	38.55 41.47φ
...21	0.0177 0.0170φ	0.0203 0.0280φ	0.1802 0.1818φ	0.1624 0.1497φ	0.3426 0.3316φ	52.60 54.84φ	41.19 43.76φ
...30	0.0114 0.0118φ	0.0189 0.0195φ	0.1161 0.1262φ	0.1512 0.1460φ	0.2673 0.2722φ	43.43 46.37φ	29.81 33.21φ
...61	0.0070 0.0060φ	0.0164 0.0170φ	0.0576 0.0642φ	0.1312 0.1272φ	0.1888 0.1914φ	30.60 33.52φ	13.90 17.21φ
...68	0.0091 0.0097φ	0.0204 0.0229φ	0.0927 0.1037φ	0.1683 0.1723φ	0.2610 0.2760φ	35.52 37.57φ	22.48 22.25φ
...14	0.0065 0.0070φ	0.0199 0.0261φ	0.0662 0.0749φ	0.1640 0.1959φ	0.2302 0.2708φ	28.75 27.65φ	11.60 9.90φ

TABLE 4.6

Material-Calcite

$D_o = 19.32$ mm, $D_u = 11.54$

Set 1

1. Wt. of solids in O/F = 17.38 gms
2. Wt. of solids in U/F = 19.07 gms

percentage of solids in feed = 5.38 percent

Set 2

1. Wt. of solids in O/F = 18.0 gms
2. Wt. of solids in U/F = 19.95 gms

percentage of solids in feed = 6 perc

(φ corresponds to results for second set)

ze in	Wt. of solids in U/F (gms)	Wt. of solids in O/F (gms)	Wt.% solids going to U/F	Wt.% solids going to O/F	Feed (gms)	E_a	E_c
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
36	0.0298	0.0142	0.2845	0.1219	0.4064	70.01	60.75
	0.0290φ	0.0116φ	0.2768φ	0.0998φ	0.3766φ	73.50φ	65.04φ
76	0.0210	0.0154	0.1814	0.1323	0.3137	57.81	44.78
	0.0200φ	0.0191φ	0.1920φ	0.1638φ	0.3558φ	53.96φ	38.75φ
21	0.0128	0.0156	0.1222	0.1344	0.2566	47.62	31.44
	0.0145φ	0.0172φ	0.1385φ	0.1475φ	0.2360φ	48.39φ	31.91φ
80	0.0147	0.0130	0.1398	0.1127	0.2525	55.37	41.59
	0.0150φ	0.0140φ	0.1683φ	0.2508φ	0.4191φ	40.15φ	21.04φ
61	0.0109	0.0136	0.1037	0.1179	0.2216	46.79	30.36
	0.0105φ	0.0140φ	0.1683φ	0.1498φ	0.3180φ	52.91φ	37.88φ
68	0.0107	0.0170	0.1021	0.1471	0.2492	40.98	22.75
	0.0110φ	0.0192φ	0.1056φ	0.1644φ	0.2700φ	39.10φ	19.66φ
.14	0.0057	0.0120	0.0544	0.1034	0.1578	34.48	14.24
	0.0071φ	0.0128φ	0.0682φ	0.1102φ	0.1784φ	38.20φ	18.47φ

TABLE 4.7

Material - Calcite

$D_o = 12.9$ mm, $D_u = 12.1$ mm

Set 1

1. Wt. of solids in O/F = 8.8 gms
2. Wt. of solids in U/F = 16.9 gms

percentage of solids in feed = 6 percent

Set 2

1. Wt. of solids in O/F =8.7 gms
2. Wt. of solids in U/F =17.0 gms

percentage of solids in feed = 6 perce

(φ corresponds to results for second set)

e in	Wt. of solids in U/F (gms)	Wt. of solids in O/F (gms)	Wt. % solids going to U/F	Wt. % solids going to O/F	Feed (gms)	E_a	E_c
1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
6	0.0407 0.0401$^{\varphi}$	0.0706 0.0726$^{\varphi}$	0.4866 0.4779$^{\varphi}$	0.4400 0.4546$^{\varphi}$	0.9267 0.9325$^{\varphi}$	52.51 51.25$^{\varphi}$	47.39 45.98$^{\varphi}$
77	0.0243 0.0250$^{\varphi}$	0.0471 0.0345$^{\varphi}$	0.2905 0.2980$^{\varphi}$	0.2934 0.2155$^{\varphi}$	0.5839 0.5134$^{\varphi}$	49.75 58.03$^{\varphi}$	44.38 53.50$^{\varphi}$
21	0.0139 0.0145$^{\varphi}$	0.0173 0.0150$^{\varphi}$	0.1662 0.2252$^{\varphi}$	0.1098 0.0961$^{\varphi}$	0.2760 0.3214$^{\varphi}$	60.20 70.08$^{\varphi}$	55.91 65.74$^{\varphi}$
30	0.0107 0.0121$^{\varphi}$	0.0201 0.0266$^{\varphi}$	0.1279 0.1442$^{\varphi}$	0.1250 0.1667$^{\varphi}$	0.2529 0.3109$^{\varphi}$	50.57 46.39$^{\varphi}$	45.24 40.60$^{\varphi}$
19	0.0077 0.0071$^{\varphi}$	0.0240 0.0201$^{\varphi}$	0.0920 0.0846$^{\varphi}$	0.1493 0.1259$^{\varphi}$	0.2313 0.2105$^{\varphi}$	38.12 40.20$^{\varphi}$	31.45 33.74$^{\varphi}$
72	0.0051 0.0059$^{\varphi}$	0.0226 0.0238$^{\varphi}$	0.0609 0.0705$^{\varphi}$	0.1408 0.1492$^{\varphi}$	0.2017 0.2196$^{\varphi}$	30.19 32.11$^{\varphi}$	22.67 24.78$^{\varphi}$
16	0.0061 0.0068$^{\varphi}$	0.0375 0.0550$^{\varphi}$	0.0729 0.0810$^{\varphi}$	0.2334 0.3462$^{\varphi}$	0.3062 0.4272$^{\varphi}$	23.81 18.97$^{\varphi}$	15.58 10.22$^{\varphi}$

Material-Calcite

D_o = 19.32 mm, D_u = 12.1 mm

Set 1

1. Wt. of solids in O/F = 11.10 gms
2. Wt. of solids in U/F = 21.44 gms

percentage of solids in feed = 6.5 percent

Set 2

2 1. Wt. of solids in O/F = 11.0 gms
2. Wt.of solids in U/F = 21.40 gms

percentage of solids in feed = 6.5 perc

(φ corresponds to result for second set)

Size in μ	Wt. of solids in U/F(gms)	Wt.of solids in O/F(gms)	Wt.% solids going to U/F	Wt.% solids going to O/F	Feed	E_a	E_c
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
48.36	0.0427 0.0439φ	0.0777 0.0615φ	.5115 0.5164φ	0.4796 0.3944φ	0.9911 0.9108φ	51.61 56.70φ	44.58 50.46φ
33.77	0.0208 0.0201φ	0.0399 0.0371φ	0.2492 0.2365φ	0.2477 0.2383φ	0.4969 0.4748φ	50.15 49.8φ	42.96 42.56φ
27.21	0.0188 0.0200φ	0.0427 0.0449 φ	0.2252 0.2360φ	0.2646 0.2884φ	0.4898 0.5244φ	45.98 45.00φ	38.13 37.07φ
20.82	0.0162 0.0179φ	0.0402 0.0483φ	0.1941 0.2106φ	0.2572 0.3004φ	0.4513 0.5110φ	43.00 41.21 φ	34.80 32.35φ
14.53	0.0106 0.0120φ	0.0221 0.0258φ	0.1270 0.1412φ	0.1376 0.1657φ	0.2646 0.3069φ	48.00 46.00φ	40.44 38.21φ
11.71	0.0034 0.0049φ	0.0099 0.0165φ	0.0407 0.0587φ	0.0617 0.1057φ	0.1024 0.1644φ	39.76 35.70φ	31.00 26.43φ
8.15	0.0054 0.0048φ	0.0300 0.0331φ	0.0647 0.0565φ	0.1861 0.2124φ	0.2508 0.2689φ	25.79 21.00φ	15.00 9.62φ

TABLE 4.9

Material-Calcite

$D_o = 11.1$ mm, $D_u = 12.8$ mm

Set 1

1. Wt. of solids in O/F = 9.97 gms
2. Wt. of solids in U/F = 23.80 gms

Percentage of solids in feed = 9.0 percent

Set 2

1. Wt. of solids in O/F = 10.0 gms
2. Wt. of solids in U/F = 23.28 gms

Percentage of solids in feed = 9 percent

(φ corresponds to results for second set)

ize in μ	Wt. of solids in U/F (gms)	Wt. of solids in O/F (gms)	Wt. % solids going to U/F	Wt. % solids going to O/F	Feed (gms)	E_a	E_c
8.36	0.0454	0.0626	0.5736	0.3497	0.9233	62.13	55.26
	0.0451 φ	0.0640 φ	0.6431 φ	0.2917 φ	0.9349 φ	68.80 φ	64.61 φ
3.71	0.0260	0.0362	0.3205	0.2021	0.5226	61.32	54.37
	0.0252 φ	0.0370 φ	0.3288 φ	0.1685 φ	0.4973 φ	66.12 φ	61.57 φ
2.21	0.0169	0.0285	0.2162	0.1530	0.3692	58.57	51.05
	0.0170 φ	0.0280 φ	0.1815 φ	0.1142 φ	0.2957 φ	61.39 φ	56.21 φ
0.82	0.0116	0.0186	0.1399	0.1033	0.2432	57.54	49.84
	0.0110 φ	0.0189 φ	0.1736 φ	0.1031 φ	0.2767 φ	62.74 φ	57.74 φ
4.52	0.0087	0.0154	0.1183	0.0819	0.2002	59.07	51.65
	0.0094 φ	0.0150 φ	0.1210 φ	0.0458 φ	0.1668 φ	72.56 φ	68.87 φ
1.73	0.0087	0.0257	0.1114	0.1380	0.2494	44.70	35.32
	0.0101 φ	0.0267 φ	0.1285 φ	0.1456 φ	0.2741 φ	46.90 φ	37.27 φ
8.17	0.0092	0.0692	0.1179	0.3810	0.4989	23.63	10.68
	0.0098 φ	0.0573 φ	0.1247	0.3122 φ	0.4369 φ	28.55 φ	15.59 φ

TABLE 4.16

Material-Calcite

$D_o = 12.9$ mm, $D_u = 12.8$ mm

Set 1

1. Wt. of solids in O/F = 10.90 gms
2. Wt. of solids in U/F = 26.15 gms

Percentage of solids in feed = 7.08 percent

Set 2

1. Wt. of solids in O/F=10.75 gms
2. Wt. of solids in U/F=26.58 gms

Percentage of solids in feed= 7 percent

(φ corresponds to results for second set)

Size in μ	Wt. of solids in U/F (gms)	Wt. of solids in O/F (gms)	Wt. % solids going to U/F	Wt. % solids going to O/F	Feed (gms)	E_a	E_c
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
48.36	0.0489	0.0580	0.6344	0.3131	0.9475	66.95	62.74
	0.0490φ	0.0598φ	0.4293φ	0.6118φ	1.0411φ	41.23φ	26.87φ
33.77	0.0244	0.0322	0.3236	0.1686	0.4922	65.75	61.39
	0.0250φ	0.0335φ	0.2843φ	0.3751φ	0.6593φ	43.12φ	29.22φ
27.21	0.0145	0.0227	0.1787	0.1204	0.2991	59.73	54.61
	0.0138φ	0.0230φ	0.1374φ	0.2316φ	0.3690φ	37.23φ	21.89φ
20.82	0.0127	0.0205	0.1700	0.1058	0.2767	61.77	56.90
	0.0132φ	0.0311φ	0.1704φ	0.1643φ	0.3347φ	50.90φ	44.64φ
14.53	0.0089	0.0220	0.1142	0.1188	0.2330	49.00	42.16
	0.0092φ	0.0253φ	0.1188φ	0.1339φ	0.2527φ	47.00φ	40.25φ
11.7	0.0087	0.0340	0.1116	0.1821	0.2937	38.01	29.69
	0.0110φ	0.0480φ	0.1420φ	0.2558φ	0.3978φ	35.70φ	27.51φ
8.15	0.0068	0.0550	0.0873	0.2958	0.3831	22.78	12.67
	0.0075φ	0.0731φ	0.0968φ	0.3873φ	0.4841φ	20.00φ	9.81φ

TABLE 4.11

Sizing Analysis by Andreasen Pipette Method

Material-Calcite

$D_o = 19.32$ mm, $D_u = 12.8$ mm

Set 1

1. Wt. of solids in O/F = 18.28 gms
2. Wt. of solids in U/F = 20.18 gms

Percentage of solids in feed = 5.7 percent

Set 2

1. Wt.of solids in O/F = 18.4 gms
2. Wt. of solids in U/F= 20.2 gms

Percentage of solids in feed = 6 percent

(φ corresponds to results for second set)

ze in μ	Wt.of solids in U/F (gms)	Wt.of solids in O/F(gms)	Wt.% solids going to U/F	Wt. % solids going to O/F	Feed (gms)	E_a	E_c
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
3.36	0.050 0.051φ	0.0508 0.0712φ	0.4770 0.6256φ	0.4390 0.6648φ	0.916 1.2904φ	52.07 48.48φ	40.36 43.48φ
3.76	0.0298 0.0290φ	0.0438 0.0430φ	0.2759 0.3922φ	0.3727 0.5332φ	0.6486 0.9754φ	42.54 40.21φ	28.53 34.41φ
7.21	0.0144 0.0148φ	0.0268 0.0270φ	0.1408 0.1412φ	0.2340 0.2342φ	0.3748 0.3754φ	37.57 38.02φ	22.35 32.12φ
20.80	0.0164 0.0147φ	0.0345 0.0349φ	0.1565 0.1400φ	0.3025 0.3030φ	0.4590 0.4430φ	34.09 31.60φ	17.98 14.93φ
13.61	0.0168 0.0170φ	0.0137 0.0135φ	0.1618 0.1665φ	0.1170 0.1162φ	0.2788 0.2827φ	58.03 58.90φ	47.79 49.00φ
11.68	0.0118 0.0115φ	0.0165 0.0250φ	0.1094 0.1093φ	0.1424 0.2168φ	0.2518 0.3261φ	43.44 33.51φ	29.62 17.30φ
8.14	0.0053 0.0075φ	0.0152 0.0072φ	0.0504 0.0307φ	0.1310 0.1077φ	0.1814 0.1383φ	27.78 22.17φ	10.13 14.62φ

Sizing Analysis by Andreasen Pipette Method
Material-Silica
I_o = 11.1 mm, D_u = 11.54 mm

Set 1

1. Wt. of solids in O/F = 14.445 gms
2. Wt. of solids in U/F = 21.90 gms

Percentage of solids in feed = 7.2 percent

Set 2

1. Wt. of solids in O/F = 16.4 gms
2. Wt. of solids in U/F = 22.8 gms

Percentage of solids in feed = 7.18 perc

(φ corresponds to results for second set)

Size in μ	Wt. of solids in U/F (gms)	Wt. of solids in O/F (gms)	Wt. % solids going to U/F	Wt. % solids going to O/F	Feed (gms)	E_a	E_c
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
52.73	0.0571	0.0920	0.6081	0.7036	1.3117	46.36	41.08
	0.0575 φ	0.0925 φ	0.6103 φ	0.7168 φ	1.3271 φ	46.00 φ	40.75 φ
36.81	0.0358	0.0809	0.3701	0.6215	0.9916	37.33	31.17
	0.0350 φ	0.0817 φ	0.3816 φ	0.6175 φ	0.9992 φ	38.20 φ	31.26 φ
29.67	0.0287	0.0704	0.3014	0.5431	0.8445	35.69	29.37
	0.0285 φ	0.0714 φ	0.2473 φ	0.5807 φ	0.8280 φ	29.87 φ	22.00 φ
22.68	0.0168	0.0654	0.1703	0.5074	0.6776	25.13	17.77
	0.0161 φ	0.0667 φ	0.1866 φ	0.4317 φ	0.6183 φ	30.17 φ	22.34 φ
15.81	0.0152	0.0367	0.1692	0.2769	0.4461	37.93	31.83
	0.0160 φ	0.0364 φ	0.0927 φ	0.2753 φ	0.3680 φ	25.20 φ	16.80 φ
12.73	0.0130	0.0194	0.1322	0.1438	0.2760	47.90	42.78
	0.0125 φ	0.0195 φ	0.0426 φ	0.1640 φ	0.2066 φ	20.64 φ	11.73 φ
8.88	0.0028	0.0149	0.0307	0.1171	0.1478	20.75	12.96
	0.0029 φ	0.0154 φ	0.0265 φ	0.1170 φ	0.1435 φ	18.47 φ	9.63 φ

TABLE 4.13

Sizing Analysis by Andreasen Pipette Method

Material - Silica

D_o = 12.9 mm, D_u = 11.54 mm

Wt. of solid in O/F = 14.50 gms.

Wt. of solid in U/F = 20.55 gms.

Percentage solids in feed = 7.5%

Size in µ	Wt. of solids in U/F (gms)	Wt. of solid in U/F (gms)	Wt. % solid goin to U/F	Wt.% solid going to O/F	Feed	E_a	E
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
52.73	0.0414	0.0973	0.5460	0.4800	1.026	53.21	48.
36.81	0.0278	0.0810	0.3652	0.4023	0.7675	47.50	41.
29.67	0.0232	0.0772	0.3050	0.3842	0.6892	44.38	38.
22.68	0.0175	0.0574	0.2315	0.2865	0.5180	45.00	38.
15.81	0.0087	0.0366	0.1150	0.1822	0.2972	38.78	31.
12.73	0.0060	0.0218	0.0795	0.1329	0.2124	37.40	30.
8.88	0.00575	0.0609	0.0760	0.3040	0.3800	20.00	11.

Table 4.14

Sizing Analysis by Andreason Pipette Method

Material Silica

D_o = 19.32 mm, D_u = 11.54 mm

Wt. of solids in O/F = 21.353 gms.

Wt. of solids in U/F = 29.750 gms.

Percentage solids in feed = 9.0 %

Size in μ	Wt. of solids in U/F gms.	Wt. of solids in O/F gms.	Wt.% solids goin to U/F	Wt. % solids going to O/F	Feed	E_a	E_c
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
52.73	0.0541	0.0775	0.5740	0.5900	1.0590	54.32	45.50
36.81	0.0304	0.0606	0.3220	0.4600	0.7820	41.20	29.75
29.67	0.0153	0.0343	0.1620	0.2430	0.4050	40.05	28.30
22.68	0.0128	0.0277	0.1355	0.2100	0.3455	39.42	27.60
15.81	0.0121	0.0175	0.1282	0.2308	0.3590	35.82	23.31
12.73	0.0090	0.0241	0.09525	0.18275	0.2820	33.80	20.85
8.88	0.0072	0.0221	0.0763	0.1677	0.2840	26.92	12.65

TABLE 4.15

Sizing Analysis by Andreasen Pipette Method
Material-Silica
I_o = 11.10 mm, D_u = 12.1 mm

Set 1

1. Wt.of solids in O/F = 19.15 gms
2. Wt.of solids in U/F = 30.20 gms

Percentage of solids in feed = 9.25 percent

Set 2

1. Wt.of solids in O/F= 14.5 gms
2. Wt.of solids in U/F= 21.5 gms

Percentage of solids in feed = 9 perce

(φ corresponds to results for second set)

Size in μ	Wt.of solids in U/F(gms)	Wt.of solids in O/F(gms)	Wt.% solids going to U/F	Wt.% solids going to O/F	Feed (gms)	E_a	E_c
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
52.73	0.0542	0.0761	0.5465	0.4866	1.0331	52.90	47.61
	0.0549^{φ}	0.0772^{φ}	0.5961^{φ}	0.5654^{φ}	1.1615^{φ}	51.33^{φ}	47.26^{φ}
36.81	0.0436	0.0700	0.4851	0.4939	0.9790	49.55	42.71
	0.0423^{φ}	0.0710^{φ}	0.4593^{φ}	0.5199^{φ}	0.9793^{φ}	46.90^{φ}	42.47^{φ}
29.67	0.0210	0.0623	0.2337	0.4395	0.6732	34.71	25.86
	0.0218^{φ}	0.0620^{φ}	0.2367^{φ}	0.4540^{φ}	0.6908^{φ}	34.27^{φ}	28.79^{φ}
22.68	0.0165	0.0508	0.1836	0.3584	0.5420	33.87	24.91
	0.0170^{φ}	0.0510^{φ}	0.1946^{φ}	0.3735^{φ}	0.5581^{φ}	33.08^{φ}	27.49^{φ}
15.81	0.0098	0.0253	0.1090	0.1785	0.2875	37.92	29.50
	0.0089^{φ}	0.0255^{φ}	0.0966^{φ}	0.1867^{φ}	0.2834^{φ}	34.10^{φ}	28.61^{φ}
12.73	0.0130	0.0256	0.1446	0.1199	0.2646	54.67	48.52
	0.0129^{φ}	0.0165^{φ}	0.1401^{φ}	0.1805^{φ}	0.3206^{φ}	43.69^{φ}	36.04^{φ}
8.88	0.0088	0.0459	0.1188	0.3420	0.4608	25.78	17.46
	0.0090^{φ}	0.0482^{φ}	0.0977^{φ}	0.3258^{φ}	0.4285^{φ}	23.07^{φ}	12.64^{φ}

TABLE 4.16

Sizing Analysis by Andreasen Pipette Method

Material-Silica

$l_o = 12.90$ mm, $D_u = 12.10$ mm

Wt. of solids in O/F = 14.02 gms
Wt. of solids in U/F = 34.45 gms
Percentage of solids in feed = 8.3 percent

Size in μ	Wt. of solids in J/F (gms)	Wt. of solids in O/F (gms)	Wt. % solids going to O/F	Wt. % solids going to O/F	Feed (gms)	E_a	E_c
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
52.73	0.042	0.0751	0.5428	0.3950	0.9377	57.88	54.55
36.81	0.0368	0.0755	0.4756	0.3971	0.8726	54.50	50.90
29.67	0.0169	0.0624	0.2184	0.3282	0.5466	39.96	35.22
22.68	0.0162	0.0463	0.2093	0.2435	0.4528	46.23	41.98
15.81	0.0057	0.0280	0.0737	0.1473	0.2209	33.34	28.08
12.73	0.0065	0.0401	0.0840	0.2112	0.2952	28.44	22.79
8.88	0.0051	0.0550	0.0646	0.2900	0.3546	18.21	17.75

TABLE 4.17

Sizing Analysis by Andreasen Pipette Method
Material-Silica

L_o = 19.32 mm, D_u = 12.1 mm

Wt. of solids in O/F = 35.2 gms
Wt. of solids in U/F = 20.0 gms
Percentage of solids in feed = 7.18 percent

Size in μ	Wt. of solids in U/F (gms)	Wt. of solids in O/F (gms)	Wt.% solids going to U/F	Wt.% solids going to O/F	Feed (gms)	E_a	E_c
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
52.73	0.0516	0.0825	0.5983	0.5435	1.1417	52.40	39.77
36.81	0.0335	0.0730	0.3884	0.4809	0.8693	44.68	30.00
29.67	0.0298	0.0658	0.3455	0.4335	0.7790	44.35	29.59
22.68	0.0243	0.0511	0.2817	0.3366	0.6184	45.56	31.12
15.81	0.0158	0.0258	0.1832	0.1700	0.3531	51.87	39.10
12.73	0.0135	0.0435	0.1565	0.2871	0.4436	35.28	18.10
8.88	0.0098	0.0510	0.1136	0.3372	0.4508	25.20	5.35

TABLE 4.18

Material-Silica

D_o = 11.10 mm, D_u = 12.8 mm

Set 1

1. Wt.of solids in O/F = 22.1 gms
2. Wt.of solids in U/F = 30.55 gms

Percentage of solids in feed = 9 percent

Set 2

1. Wt. of solids in O/F = 18.65 gms
2. Wt.of solids in U/F = 29.65 gms

Percentage of solids in feed = 9.05 percent

(φ corresponds to results for second set)

Size in μ	Wt.of solids in U/F (gms)	Wt.of solids in O/F (gms)	Wt.% solids going to U/F	Wt. % solids going to O/F	Feed (gms)	E_a	E_c
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
52.73	0.0516 0.0520φ	0.0862 0.0865φ	0.5444 0.5804φ	0.6579 0.6073φ	1.2022 1.1877φ	45.28 48.87φ	39.30 44.67φ
36.81	0.0367 0.0370φ	0.0777 0.0780φ	0.3872 0.4130φ	0.5930 0.5476φ	0.9802 0.9606φ	39.50 42.99φ	32.89 38.32φ
29.67	0.0236 0.0279φ	0.0742 0.0750φ	0.3017 0.3114φ	0.5663 0.5265φ	0.8680 0.8379φ	34.76 37.16φ	27.63 32.01φ
22.68	0.0212 0.0210φ	0.0504 0.0510φ	0.2237 0.2344φ	0.3846 0.3580φ	0.6083 0.5924φ	36.77 39.56φ	29.86 34.61φ
15.81	0.0173 0.0175φ	0.0322 0.0333φ	0.1825 0.1953φ	0.2457 0.2338φ	0.4283 0.4291φ	42.62 45.52φ	36.35 41.05φ
12.73	0.0159 0.0163φ	0.0396 0.0279φ	0.1677 0.1708φ	0.3024 0.1958φ	0.4701 0.3666φ	35.67 46.59φ	28.64 42.21φ
8.88	0.0079 0.0075φ	0.0285 0.0420φ	0.0833 0.0837φ	0.2173 0.2963φ	0.3006 0.3800φ	27.71 22.01φ	8.53 15.61φ

TABLE 4.19

Sizing Analysis by Andreasen Pipette Method
Material-Silica

D_o = 12.9 mm, D_u = 12.8 mm

Wt. of solids in O/F = 16.45 gms
Wt. of solids in U/F = 18.55 gms
Percentage of solids in feed = 6.21 percent

Size in μ	Wt. of solids in U/F (gms)	Wt. of solids in O/F (gms)	Wt.% solids going to U/F	Wt.% solids going to O/F	Feed (gms)	E_a	E_c
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
52.73	0.0635	0.0770	0.6119	0.6580	1.2699	48.19	44.18
36.81	0.0413	0.0831	0.3980	0.7529	1.1508	34.58	29.52
29.67	0.0254	0.0759	0.2448	0.6486	0.8934	27.40	21.78
22.68	0.0199	0.0630	0.1918	0.5384	0.7301	26.26	20.56
15.81	0.0080	0.0307	0.0771	0.2623	0.3394	22.71	16.73
12.73	0.0097	0.0478	0.0935	0.4089	0.5024	18.61	12.31
8.88	0.0069	0.0410	0.0665	0.3507	0.4172	15.94	9.43

TABLE 4.20

Sizing Analysis by Andreasen Pipette Method
Material-Silica
I_o = 19.32 mm, D_u = 12.8 mm

Wt. ofssolids in U/F = 28.70 gms
Wt. of solids in O/F = 22.05 gms
Percentage of solids in feed = 7.08 percent

Size in μ	Wt. of solids in U/F (gms)	Wt. of solids in O/F (gms)	Wt. % solids going to U/F	Wt. % solids going to U/F	Feed (gms)	E_a	E_c
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
52.73	0.0415	0.0864	0.4267	0.6825	1.1092	38.47	28.00
36.81	0.0375	0.0735	0.3856	0.5806	0.9662	39.91	29.68
29.61	0.0186	0.0629	0.1912	0.4961	0.6873	27.82	15.54
22.68	0.0144	0.0450	0.1080	0.3555	0.5035	29.40	17.39
15.81	0.0105	0.0223	0.1080	0.1762	0.2841	38.00	27.45
12.73	0.0092	0.0164	0.0946	0.1296	0.2242	42.20	32.37
8.88	0.0042	0.0122	0.0432	0.0964	0.1396	30.94	19.19

CHAPTER 5

SUMMARY AND CONCLUSIONS

The main object of the present investigation is to study the performance characteristics of laboratory size compound water cyclone on the lines similar to those for classifier cyclones, with an ultimate objective to derive some scale up equations for the design of compound water cyclone.

In the present study, a 3'' compound washer cyclone was arranged in a closed circuit with a sand pump via a cylindrical pulp tank. Vortex finders of diameter 11.10 mm, 12.9 mm, and 19.32 mm and spigots of diameters 11.54 mm, 12.1 mm and 12.8 mm were used for the experimental runs. Three different materials calcite, coal and silica were used for the tests. The pulp of required pulp density was prepared and fed into the cyclone. When the steady state was attained, the overflow and underflow samples were collected for a fixed period of time. The samples collecte were analysed by Andreasen Pipette Method for sizing analys The graphs of throughput vs. vortex finder diameter and throughput vs. spigot diameter were plotted for calcite, coa and silica on log-log scales. Within the experimental errc limits these curves were straight lines. The throughput of compound washer as a function of vortex finder and spigc

could be represented by the following equation

$$Q = K_6 \; (D_o)^{0.678} \; (D_u)^{0.24} \qquad (6.1)$$

The plots of water distribution (Figs. 4.7 and 4.8) were obtained for calcite and silica and the following relationship between water in overflow and water in feed was found to be matching well with the experimental data

$$WOF = x_1 \log WF + C_7$$

The plots of actual efficiency, corrected efficiency and reduced efficiency were obtained and the nature of actual, corrected and reduced efficiency curves for compound washer cyclone was found to be similar to that of hydrocyclone classifiers. Therefore, the efficiency equations which are valid for hydrocyclone classifiers can also be applicable to the compound washer cyclones.

Conclusions

From the above discussions following conclusions can be drawn:

1. Throughput increases with increase in both vortex finder and spigot diameters. Following relation seems to be valid

$$Q = K_6 \; (D_o)^{0.678} (D_u)^{0.24}$$

2. Water distribution in overflow as well as feed are related in the following manner.

$$WOF = x_1 \log WF + C_7$$

where x_1, a constant, is a function of material, and constant, C_7, is a function of spigot diameter.

3) The actual, corrected and reduced efficiency curves are found of more or less same nature as for the hydrocyclone classifiers.

REFERENCES

1. C. Krygsman, The Dutch State Mine Cyclone Washer, Symp. Coal Preparation Leeds (1952) pp. 83-112.

2. Staas, M. Int. Min.Dressing Cong., Stockholm, Paper II:2 (1957)

3. J. Visman, Cleaning Fine Coal in a 3 stage water cyclone circuit, Trans. CIM Bulletin, V-54, 1961, pp.442-446.

4. J. Visman -'Bulk Processing of fine materials by compound water cyclones', Transaction CIM bulletin Vol.59, 1966, p. 333-346.

5. Dahlstrom, D.A.-'Cyclone operating factors and capacities on coal an refuse slurries', Trans. AIME, Vol.184, p. 331 (1949)

6. Kelsall, D.F.-'A study on the motion of solid particles in a hydraulic cyclone', Trans.Inst.Chem.Engrs.(London) V-30,p.87 (1952).

7. Chaston, I.R.M.-'A simple formula for calculating the approximate capacity of a hydrocyclone', Bulletin of I.M.M. 615, (1958).

8. Fahlstrom, P.H.-'Studies on hydrocyclone as a Classifier' 6th Int. Min.Proc.Congr.(Cannes),p.87,(1963)

9. Lynch, A.J. and Rao, T.C.-'Studies on the operating Characteristics of hydrocyclone classifier' Indian J. of Tech. 4, V-6, p.106 (1968).

10. Lynch, A.J. and Rao, T.C.- 'Modelling and scale-up of hydrocyclone classifiers' 11th International Mineral Processing Congress, Sardinia, paper No.9, p.-24,(May 197

11. Peachey, C.G.-'Distribution of Water in large diameter cyclones under operating conditions', Int.Min.Proc.Congr. (London),Group II, paper-8, p.147, (1960).

12. Debkanungo, P.S. and Rao,T.C.-'A study on the performance of 3'' hydrocyclone classifier' Canadian Min.Met.Bull. Vol.66, p.78, 1973.

13. Yoshioka, N. and Hoha, Y., Chem.Engg.Japan,19,1955, p. 632.

14. Bradley, D., Chapter 6 in the Hydrocyclone, Pergamon Press (1965).

15. Cohen, E., Trans.Inst. Min.Met. (London) 71, 1962, p. 524.

16. Rao, K.N. and Rao, T.C.- 'Analysis of reduced efficiency curve of a hydrocyclone', Indian J. of Tech. Vol.13, No.10, p. 446 (Oct.1975).

17. Kelsall, D.F.-'A further study of hydraulic Cyclone', Chem. Eng. Sci.,V-2, p.254 (1953).

18. Dekok, S.K., J. Chem.Met. and Min.Soc.South Africa 56, 281 (Feb.1956).

19. Moder, J.J. and Dahlstrom, D.A.- 'Fine size close specific gravity of solid separation with the liquid-solid cyclone', Chem.Engr.Progr., v-48,p-75 (1952).

20. Matschke, D.E. and Dahlstrom, D.A.- 'Energy requirements and solid elimination efficiency of miniature hydrocyclones', Chem.Engr.Progr., v-55, p-796 (1959).

21. Rao, K.N., M.Tech. Thesis, Dept. of Met.Engg. IIT Kanpur (1971).

APPENDIX

A-1 Andreasen Pipette

Andreasen pipette consists of a graduated cylindrical flask and a pipette connected to a 10 cc reservoir by means of a three way stop cock. The ground glass stopper has a small opening permitting influx of air into the sedimentation flask when samples are withdrawn. The tip of the pipette is at the zero mark, when the ground glass stopper is properly seated.

With this method, samples of suspension are removed from a given level at different times after the sedimentation has started, and the concentration of the dispersed material in them is determined by evaporation and weighing.

Particle Size Determination

If C_o is the concentration of the dispersed material and C_t is the concentration at time t, then C_t/C_o is the fraction of original quantity of material having a particle size smaller than the size corresponding to a falling velocity h/t, since all larger sizes will have fallen below the tip while concentration of smaller sizes are unaltered. The equivalent diameter of this size range is expressed in microns, as

$$D_t = 141\left[\frac{h\eta}{t(\rho_S - \rho_L)}\right]^{0.5}$$

where D_t is in microns, t is the time at which the sample is collected in minutes, h is the depth below the surface at which the sample is collected in cms, η is the viscosity of the medium in poise and ρ_S and ρ_L are the specific gravities of the solid and liquid respectively.

A-2 Experimental Errors

The sources of error in size measurement using Andreasen Pipette are summarised below:

(i) losses of material during handling (drying, weighing etc.) of samples.

(ii) inaccurate measurement of time for which the samples of the overflow and underflow streams were collected.

These errors contribute to the mass flow rates of solids and water.

The main source of error in size distribution, apart from sampling is the inherent error of Andreasen Pipette method. This is that while the pipette is being filled, the tip itself causes a flow of particles from above and below the level, which it is supposed to sample, with a result that the withdrawn sample will contain not only the particles which lie above that level, but also particles which are supposed to have settled out of suspension.

A-3 Sample Calculation

From each set of experimental results it was possible to calculate the distribution of water and solid in cyclone feed and products. This is elucidated below with the results from Table 4.5

Measured quantities

a) Wt. of container(A) and overflow sample collected in time (OFT = 5 sec.) = WOF1 = 684.5 gms

b) Wt. of dry container (A) = WCONA = 277.0 gms

c) Wt. of container (B) and underflow sample collected in time (UFT = 5 sec.) = WUF1 = 399.0 gms

d) Wt. of dry container (B) WCONB = 284.0 gms

e) Wt. of dried overflow solid = OSOL1 = 16.5 gms

f) Wt. of dried underflow solid USOL1 = 21.0 gms

From this following items can be calculated as

i) Mass flow rate of overflow pulp(lbs/min) = WOF =

$$\frac{(\text{WOF1} - \text{WCONA})\text{X}60}{\text{OFT X } 453.6} = 10.7804 \text{ lbs/min.}$$

ii) Mass flow rate of underflow pulp (lbs/min)= WUF =

$$\frac{(\text{WUF1} - \text{WCONB})\text{X}60}{\text{UFT X } 453.6} = 3.0423 \text{ lbs/min.}$$

iii) Mass flow rate of solid in O/F = (OSOL) =

$$\frac{\text{OSOL1 X } 60.0}{\text{OFT x } 453.6} = 0.4365 \text{ lbs/min.}$$

iv) Mass flow rate of solid in U/F = USOL =

$$\frac{\text{USOL1} \times 60.0}{\text{UFT} \times 453.6} = 0.5556 \text{ lbs/min.}$$

v) Mass flow rate of water in O/F = OWAT =

WOF - OSOL = 10.3439 lbs/min.

vi) Mass flow rate of water in U/F = UWAT-USOL 2.4868 lbs/min.

vii) Mass flow rate of solid in feed = FSOL = OSOL + USOL

= 0.992 lbs/min.

viii) Mass flow rate of water in feed = FWAT = OWAT + UWAT

= 12.8307 lbs/min.

ix) Mass flow rate of feed pulp = WF = WOF + WUF 13.8227

= 13.8227 lbs/min.

x) Mass flow rate of feed pulp =

$$\frac{\left(\text{FWAT} + \frac{\text{FSOL}}{2.7}\right) \times 60. \times 453.6}{1000.0 \times 4.5} = 79.822 \text{ lbs/min.}$$

Calculation for actual, and corrected efficiencies

Weight solids of size (48.36 μ) going to underflow (U/F)

$$A = \frac{0.0609 \times 21}{5.5 \times 37.5} \times 100 = 0.6201$$

Weight solids of size (48.36 μ) going to overflow (O/F)

$$B = \frac{0.0527 \times 16.5}{5.5 \times 37.5} \times 100 = 0.4335$$

Therefore Feed (48.36μ) = F = A+B = 1.0536.

Actual Efficiency = E_a (48.36) =

$$\frac{\text{weight solids (48.36}\mu\text{) going to underflow}}{\text{Feed (48.36 }\mu\text{)}} \times 100$$

$$= \frac{0.6201}{1.0536} \times 100$$

$$= 58.85$$

$$R_f = \frac{\text{Weight of water in underflow}}{\text{Weight of water in feed}} \times 100$$

$$= 19.4$$

Corrected efficiency = $E_c(48.36\mu) = \dfrac{E_a(48.36)-R_f}{100-R_f} \times 100$

$$= \frac{58.85 - 19.4}{100 - 19.4} \times 100$$

$$= 48.95.$$